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PUBLISHERS,

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NEW YORK OFFICE, 206 BROADWAY.

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PRIZE ESSAY.

A PRACTICAL AND THEORETICAL TREATISE

—ON—

The Detached Lever Escapement

FOR WATCHES AND TIME-PIECES.

BY MORITZ GROSSMANN.

Translated from the German by C. C. PIERCE.

REVISED, CORRECTED AND GREATLY ENLARGED.

TWENTY DIAGRAMS.

CHICAGO:
THE JEWELERS' PUBLISHING CO.
1884.

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PREFACE

THE DETACHED LEVER ESCAPEMENT forms one of the most interesting and important subjects for study in the whole range of the horological art, and is at the same time one of the most difficult to treat fully, comprehensively, and in such manner as to be easily understood. Realizing the paramount importance to the working watchmaker of a thorough comprehension of the Detached Lever Escapement, the principles of its construction, the relation of its several parts and the methods of calculation by which its relative proportions may be varied to produce certain results, the subscribers to the Prize Fund of the British Horological Institute resolved, in the month of January, 1864, that its first prize should be offered for the best treatise on this subject. This prize, of the sum of thirty guineas, or about $150, was promptly announced in a circular issued to the members of the Institute, and at once attracted the attention of Moritz Grossmann, then as now a resident of Glashutte, Saxony, a member of the Institute of many years standing, and a careful, painstaking, scientific horologist. He at once determined to compete for the prize, the more readily arriving at this determination from the fact that he had long contemplated writing a series of works upon the several branches of practical horology, embodying the result of his experience and study, and the reception accorded this essay would serve as an index to the measure of success likely to attend such publications.

Having been awarded the prize, Mr. Grossmann, encouraged by many eminent horologists, concluded to publish the work in book form, preparatory to which he greatly elaborated many portions of it and added the chapters on "Measuring Instruments," and "Materials Employed in Making Lever Escapements," thus increasing it to nearly double its original size.

In April, 1866, it was published, and immediately assumed the importance of a standard text-book upon the subject of which it treats. It has been widely read and consulted in this country as well as in Europe, the superior intelligence of American watchmakers enabling them to readily understand the work and appreciate its value; but the high price at which it has hitherto been held by European publishers has greatly limited its sale, while the difficulty of procuring it in large quantities at any price has rendered it an unprofitable publication for dealers to handle. Satisfied that a large edition, published at such a price as to place it within the reach of every working watchmaker in the country, would be appreciated by the craft, we have at great expense prepared this premium edition, and offer it to our patrons at a nominal price, making it the first of a series of technical works which, when completed, will embrace everything extant in the field of literature calculated to aid the workman in the profitable and pleasant pursuit of his calling.

THE JEWELERS' PUBLISHING COMPANY,

CHICAGO, March 1, 1884. H. A. PIERCE, *Prest.*

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CHAPTER I.

HISTORICAL NOTICES OF THE ORIGIN OF THE DETACHED LEVER ESCAPEMENT.

THE first trace of time-keeping by purely mechanical means dates back to the Tenth century, when Gerbert, Bishop of Magdeburg (subsequently Pope Sylvester II), is said to have constructed a clock going by weights and wheels.

About the year 1370 Henry Vick, whom King Charles V of France called from Germany for this purpose, made a turret-clock, the first one of which we possess complete and positive information.

Since the time of these first clocks the progress of horology has been very great, but what has been done in this way has been chiefly in perfecting the escapement and the regulating parts, while the wheelwork of the train has suffered but very little and comparatively unessential alterations. The invention of the pendulum as the regulating part of clocks and of the pendulum spring for portable timekeepers were the principal sources of transformation in the means employed for time-measuring.

Any one who sees the clocks and watches of our day, would be inclined to suppose that the first clocks were constructed with a pendulum as regulator, because this is evidently the most simple and certain system for clocks, and that the employment of the balance as a regulator has been suggested by the necessity of producing portable timekeepers, for which the pendulum would not answer.

This is, however, not the case, for the first clocks we have any historical notices of had a verge escapement with a kind of rudimentary balance as a regulator, and the employment of the pendulum for measuring the time was discovered nearly three centuries after the construction of Vick's clock, by Galileo. From this time clocks were made with the pendulum, but always with the verge escapement, this being the only one known at this period.

This progress, important as it was, became much more so by another invention ensuing from it.

The old vertical or verge escapement was very soon found unsatisfactory for clocks, by requiring too large an arc of oscillation. This circumstance led to the invention of the anchor pallets for clocks, by Hooke, about 1650. From that time the possibility existed of employing a long, heavy pendulum with small arcs of vibration.

An improvement of great value on Hooke's anchor pallets was Graham's dead-beat escapement, invented about the end of the Seventeenth century. Though the comparative value of Hooke's recoiling anchor and Graham's dead-beat escapement was a matter of earnest doubt among the most competent horologists of that time, the latter has decidedly superseded its rival, and is even now, in spite of all inventions of later date, the very best escapement for a good astronomical clock.

While these important improvements were made on the escapement of clocks, watches were constructed mostly with the old vertical escapement. The great inaccuracy in the timekeeping of such watches, though amended as much as possible by the insertion of the fusee, created many contrivances of escapements with the principal view of giving more extension to the vibrations, and by doing so, making them more independent of the variable effect of the moving force and less liable to be disturbed by the external motion which a portable timekeeper is exposed to.

Among these experiments we find a contrivance of Huyghens, in which the verge escapement is kept as it is, with the only difference that the verge, instead of carrying the balance, has a wheel riveted on its axis, pitching into a pinion, which carries the balance. This was the first rough embodiment of the idea of increasing the arc of vibration by intervening mechanism.

Another escapement with this multiplication of vibratory movement is the *rack-lever*, invented by the Abbe Hautefeuille. It is almost identical with Hooke's recoiling anchor, but on the anchor axis is mounted a toothed rack, which pitches into a pinion forming the balance staff. This method, however, was soon abandoned, after the horizontal and the duplex escapements had been invented by Graham and Dutertre.

In these two dead-beat escapements the possibility of larger vibrations was obtained, but during the excursions of the balance the tooth of the escape wheel was resting against a circular part of the balance axis. These escapements are very little influenced by the variations of the motive force, but the tooth resting against the axis produces necessarily a considerable friction, increasing with the diameter of that circular part and with the extent of the vibrations. This friction, although diminished to the smallest amount possible in the duplex escapement, necessitates the application of oil on these parts, thus making the rate of the watch dependent on the quality of the oil and on all the changes by time and atmospheric influence to which even the best oil is subject. This occasioned the most earnest efforts to make the vibrations of the balance more independent of the train and of the variable condition of the oil. Escapements were constructed effecting this purpose more or less perfectly, one of which originated through taking up the idea of Huyghens and Hautefeuille of multiplying the arc of vibration by transmitting it to the balance through a lever. The recoiling anchor employed by Hautefeuille was converted into a reposing or dead-beat anchor. By the lever on the anchor axis the very small lifting arc of this latter was transferred to the balance in such a way as to multiply it considerably and to make all connection between these two parts cease immediately after the small arc of intersection had been performed, leaving the balance quite free for all the rest of its vibration. This escapement is the *detached lever escapement;* it was invented by Mudge, about 1750, and it has served as prototype to all sorts of detached lever escapements known in our day.

A description of Mudge's detached lever escapement will be given in Chapter V, with a diagram of its original form. This escapement was at the time of its invention not fully appreciated, for Mudge himself applied it to but two of his watches. Even at the beginning of our century it was but very little known, and the horizontal and duplex escapements prevailed for first-class watches. Since that time it has been more and more employed for better classes of watches, and has now got the better of its former rivals.

Many modifications and improvements have been made on it, the most important of which will be described in the fifth and ninth chapters.

CHAPTER II.

PRELIMINARY REMARKS.

Before entering into the practical description and explanation of the lever escapement and its varieties, I think it right to say some words indicating the points of view from which I intend to treat the subject.

In the first place, I deem it necessary to assume a neutral and cosmopolitan position, not merely dwelling on the inventions and contrivances in the lever escapement originated in England and by English horologists, but describing any construction of this escapement, no matter where it has been invented or kept in use.

With respect to the order in which to describe the different varieties of the lever escapement, I have thought it best to follow the historical arrangement as much as possible, always fully describing and explaining those peculiarities which are good and commendable, and only indicating by a short description and diagram those which are of a merely historical value, and have not shown any practical advantage.

In all the points where construction and calculation are concerned, I intend to take a quite different course from that hitherto in use. This deviation from the common way will be perceived through the whole extent of this treatise, and as I think this reformation of the method of measuring and calculating the most important and useful part of it, I beg to explain here the motives that make me think so.

The manufacture of clocks and watches, especially the latter, presents a peculiar difficulty by the reduced dimensions in which the parts of a watch must be constructed. The necessity of portability restrains the size allowed to a watch within very small limits, and even those horological i struments for which no such restriction would be imposed—for instance, box chronometers—are, for good reasons, very rarely made beyond a certain conventional size, which does not obviate the difficulty above mentioned.

Now it is easy enough to draw any individual part of a watch on a large scale perfectly, according as scientific rules and good symmetry and harmony between the different parts may demand. But it is very difficult to transmit the exact proportions found in this way to the real dimensions of our work, without any essential alteration.

Every other mechanician has the advantage that he may draw his work to the real size, and very often he is even obliged to draw on a smaller scale. Besides this, he has at his disposal measuring instruments of sufficient accuracy to execute his work with the necessary exactness. But the watchmaker, on the contrary, cannot draw the objects of his manufacture except on a magnified scale, and those especially for which the greatest accuracy is required can only be drawn on a scale of 20 or 30 to 1, if the distinct illustration of all the particulars would be attained. The way and means of transferring the correct proportions of a good drawing to the real working size of watch-work are problems of great importance, though very little has been done till now to obtain a satisfactory result in this direction.

The measuring instruments, gauges, calipers and tables for every special purpose, such as are resorted to by the majority of horologists and escapement makers, are very imperfect means. The measuring instruments are for the greater part not even of a sufficient accuracy and delicacy in their construction, and are in most cases quite independent of any certain standard measure; therefore they could not be used as a vehicle of mutual understanding on questions of sizes and proportions, nor could they be employed for any calculation or reduction of these sizes. The eccentric gauge of Roberts, for instance, though described and recommended twice in the British *Horological Journal*, would be quite useless for the two cases just mentioned. For intercomparison it would not do because it would prove a very difficult thing to construct a number of these gauges to give an identical measurement, for the slightest deviation from the true difference of centers, here one-tenth inch, would always produce a difference of twice the extent. For calculation or reduction it would not answer, because there is not the slightest connection with any standard measure, and because the sizes measured by it are progressing in an increasing and decreasing ratio, so that it would be a very dangerous error to suppose, for instance, that the size 20 on this gauge would be a third of 60 or a half of 40. Besides, the range of sizes encompassed by this gauge is very limited, and will hardly exceed three or four millimetres when the d[illegible]ion is extended up to 100 parts, and the delicacy of the division is not very great, for one degree of it corresponds to an average size of 0.04 m. The instrument is also not of a nature to be used for measuring very small and frail objects, such as the ruby roller of a duplex escapement, etc., and altogether it is not to be recommended because the eccentric principle is entirely defective for this purpose. Most of the gauges and tables now in use are made only for a certain number of cases and sizes, and leave the workman quite helpless when it is required to make an escapement with different numbers of teeth, uncommon angles of lifting and in larger or smaller sizes than usual. Besides, they are very seldom based upon scientific principles, and it is a question whether many of them are not altogether incorrect.

As the Museum Committee of the British Horological Institute, by its announcement of March 20th, 1861, asked for information on the subject of a good and uniform system of measurement, being a member and a warm friend of the Institute, I thought it would be wrong not to give the description of a system known to me by many years' experience, and which I was sure would prove very useful when introduced into English watch manufacturing. I therefore sent in a paper, giving complete details on this subject, and for better illustration I also forwarded two of the measuring instruments, as a donation for the museum. The paper was published in the *Horological Journal*, No. 55, March 2nd, 1863. I demonstrated in it that the proposed system was not only very suitable as a universal standard of measuring in the watch trade, but more than that, would at the same time be the means of applying mathematical principles directly to the practical execution of watchwork.

Nobody will deny that though the advantages of a uniform measurement are very important, the possibility of transferring exact proportions to escapements, etc., is much more so; and I had not the slightest doubt that the system proposed by me, uniting these two great objects, would soon make friends in England.

The publication of the above mentioned paper was followed by a warm recommendation of the Museum Committee to introduce and employ universally the metric system. It is strange to say that this opinion of the Museum Committee has not found any adherents, and I conclude by this unexpected fact that I have not been successful in my endeavors to prove the applicability of the metric system to the solution of every problem in horology, or that perhaps a great number of practical men have gained an unfavorable impression by the calculations which for greater completeness I gave in the paper.

I think the present opportunity very favorable for showing to what extent this way of measuring and calculating is capable of application in constructing a correct lever escapement. For the double purpose of being useful to the practical workman as well as to the scientific horologist, I shall describe, in the first place, the simple graphic method; that is, the way to make a drawing on a large scale, and to reduce and transmit the sizes from the drawing to the real working proportions. At the same time I shall give the shortest and easiest forms of calculation by which the proportions are developed in a mathematical way.

Thus, I hope, every one will be able to avail himself of the advantages of this system. The practical workman who does not like to be troubled by mathematical dissertations may leave the calculative part aside and proceed in the practical way to make a drawing, which, in most cases, will not prove a great difficulty to him.

In the diagrams I have deemed it advisable to make the angle of movement of wheel and pallet 10° from drop to drop, and that on the balance 30°, these being about the average angles of all those in use.

CHAPTER III.

GENERAL OBSERVATIONS ON THE DETACHED LEVER.

The detached lever escapement shows at the first glance a very different feature from all the escapements now in use for watchwork. This difference is perceptible even to the eye of the least experienced observer, and consists chiefly in the intervening action of a lever between the escape wheel and the balance, while in all other escapements for watches (except the remontoir escapement) the escape wheel gives its impulse directly to the balance.

It might be considerad a matter of doubt whether perfection ought to be sought by creating an additional part of the escapement, and thus making it a more complicated mechanism. Still, the experience of more than half a century confirms the truly good performance of the lever escapement, and we must acknowledge on close examination that of all the escapements for watches only the duplex and detent escapements might enter into competition with it. The duplex, however, is of a rather frail nature, and very much exposed to injury by rough use of the watch and sudden movements in wearing it. The detent escapement, though of very valuable time-keeping properties, and apparently more simple, by admitting a direct impulse of the balance roller, is, by its locking and detent-spring at least as complicated, and at any rate much more difficult to execute and to keep in good order, than the lever escapement.

There is another circumstance which speaks strongly in favor of the lever escapement. The balance in this latter receives an impulse for each vibration, while the duplex and detent escapements have but one impulse for each two vibrations.

The lever escapement does not admit of constructing such very flat watches as the Swiss manufacturers produce with the horizontal escapement; but happily the predilection for such flat watches is now declining, and for watches of a more substantial size the lever escapement, of all the escapements known, is certainly the most valuable, its parts being comparatively strong and not easily injured by violent external motion, or by being repaired or cleaned by unskilled workmen.

Another and most important advantage of the lever escapement is, that, supposing a proper construction and right proportions of the weight and diameter of the balance and the force of the mainspring, it will not set on the locking, nor on the lifting, but go on immediately by itself as soon as the motive force is in action. This cannot be said of the duplex or detent escapements, though this quality must be highly appreciated in a portable timekeeper.

CHAPTER IV.

ANALYSIS OF THE DETACHED LEVER ESCAPEMENT.—ITS PARTS AND THEIR VARIOUS CONSTRUCTIONS.

A complete lever escapement is composed of and contains two distinct actions: First, the action of the wheel and pallet. Second, the action of the lever or fork and roller. These two actions are produced each by two acting parts, so that the number of those parts in the lever escapement is four. They are: The wheel, the pallet, the lever and the roller.

The wheel is flat, its teeth projecting in its own plane. The teeth are of various shapes, corresponding to the way in which the lifting is performed, and vary from a sharp pointed form to a full inclined plane. The wheel is mounted upon the escape-pinion, by which it is connected with the train.

The pallet is also of very different shape and proportion. In most cases its body lies in a tangential direction to the circle of the wheel, and shows on its extremities two projecting parts, directed towards the wheel-teeth, on which the action of these latter takes place. The parts are called the arms of the pallet. In most cases, the parts operated on by the wheel-teeth are jeweled with hard stones, to provide for greater resistance against wearing. The pallet has a hole in its centre by which it is fixed on the pallet-axis or pallet-staff, and moves with this axis.

The lever is a bar of metal, fitted by its hole on the pallet-axis, and fastened at a certain angle to the longitudinal direction of the pallet. This angle is quite arbitrary and depends entirely upon the intended arrangement of the escapement. (Chapt. VII.) If there are two arms of the lever, one of them serves merely to establish the equipoise, while the other is the acting arm. This latter has in the greatest number of lever escapements a notch cut into its extremity, wherefore it has been called the fork.

The roller, in the ordinary construction of lever escapements, carries the impulse pin, commonly made of a ruby, working into the notch of the fork. It is a round disc, fitted by its centre-hole on the balance-staff.

These four parts have have three centres of motion, the pallet and lever moving together on the same axis. They are made in manifold ways, thus constituting an indefinite number or different lever-escapements, the whole of which it would be a very tedious task to describe.

But as all these varieties result from different combinations of the various kinds of the two before-mentioned actions forming the lever-escapement, and which, being entirely separate actions, may be combined in every possible way, it will simplify the treatment of the subject, to establish a classification of these two actions, according to the various ways in which they take place, and then to explain what is required for their combination.

Therefore the various constructions of the lever escapement may be classified from two principal points of view: first, with regard to the way in which the lifting of the wheel on the pallet takes place; second, with regard to the means by which the impulsion is transferred to the balance.

CHAPTER V.

THE ACTION OF WHEEL AND PALLET.

This action consists in an alternate lifting, imparting a small vibratory motion to the pallet, by means of a diagonal driving-plane on each arm of the pallet. This lifting is not permanent, because the two driving-planes are interrupted by two planes nearly concentric to the pallet centre, so as to arrest or lock the wheel-tooth dropping against them. By the interposing of these locking-faces, the lifting of every tooth, ending with the drop of this tooth from the edge of the lifting plane on one pallet-arm, is succeeded by the resting of the corresponding tooth on the locking face of the other arm. There it remains locked, until released by an action which shall be spoken of later.

The locking-faces must have a slight deviation from the line adapted for the mere resting or locking of the wheel tooth. This deviation serves to produce a tendency of the pallet-arm to be drawn forward towards the centre of the wheel, thus securing the detachment of the vibrations of the balance by preventing the pallet from leaving its position of rest by the slightest movement of the watch. This tendency of the locking-faces is commonly called the "draw."

The lifting of the pallet, which constitutes the principal part of the wheel and pallet-action, can be produced in three different ways:

1. The inclined planes being on the pallet and the wheel-teeth having a simply pointed form. (Ratchet-teeth.)

2. The inclined planes being on the wheel-teeth and the pallet presenting two thin pins or edges.

3. The inclined planes being partly on the pallet and partly on the wheel teeth. (Club-teeth.)

The system of making the inclined planes only on the pallet arms seems to be the oldest plan of lever escapement for watches. Mudge, who, according to our opinion, executed the first detached lever escapement, made his pallet in that way, and the same system, with very trifling alterations, is still in use in our day in almost all English lever watches.

Mudge's pallet was made to embrace five teeth (of a wheel of twenty teeth) (Diagram 1), which number has been reduced to three, with a view of having the pallet of as little weight as possible, and to reduce the friction of the acting parts to a smaller amount. The locking faces of Mudge's pallet were merely arcs of circles concentric to the pallet centre, the "draw" being an improvement of later date.

Diagrams 2 and 3 show two different kinds of lever escapements with the lifting planes on the pallet. In Diagram 2. the arms of the pallet are of equal length, and consequently the action of the wheel teeth takes place at the same centre distance on both of them. (Circular pallet.) But the resistance in unlocking is with this construction very different, and much less on the second arm than on the first, or entrance arm, owing to the different radii of the locking circles. This is a very serious obstacle to a regular performance of the watch, and therefore all the better escapements are made in the way shown by Diagram 3. Here are the two locking faces at the same distance from the centre of pallet, and the unlocking will consequently be done on each side with the same amount of force.

The lever escapement with pointed or ratchet teeth has the considerable advantage of going with the least possible amount of friction, the point of the tooth sliding along a polished surface, generally made of hard stone, to diminish friction and prevent wearing of the acting parts. Besides it has not so much to suffer under the pernicious influence of the adhesion of thickening oil, which exemption makes it keep a very steady rate. Almost all English watches have ratchet wheels. Still, it may be said against this system that there must be necessarily a certain quantity of drop, which in this dead-beat escapement is a complete loss, of power. The very delicate points of the ratchet wheel teeth are also very liable to being spoiled by unskillful hands.

The lever escapement with the lifting planes on the wheel teeth is, from a theoretical point of view, a very perfect action, because its lifting and locking are performed exactly at the same centre distance and under the same angles.

This variety of the lever escapement has been adopted in a certain kind of German watches, but has been hitherto very little used and known.

The most simple form of it is shown in Diagram 4. The pallet consists of two arms of brass, carrying each a very thin, hard-tempered steel pin, standing upright out of its upper surface. The pallet and lever are one and the same piece. The lifting faces on the wheel teeth are rounded, and must be carefully polished, as well as the locking faces of the teeth. The draw in this escapement is effected by a slight deviation of the locking faces (on the foreside of the wheel-teeth) from the straight line towards the centre of the wheel. Watches with this escapement perform very well. There may be objection to the acting parts not being jeweled, and consequently liable to wear from use, but it is a fact that such escapements, with an escape-wheel of tempered steel, show no symptoms of deterioration of the pins after many years of service; and even if such a thing should happen, it is a very easy matter to insert new pins.

A lever of this kind can be made in very delicate proportions, and weighing less than any pallet and lever of another kind. This escapement ought to be more generally known, for, requiring no jewels, it can be made so cheaply, and with the tools to be found in every watchmaker's workshop, that it might prove very useful, especially in cases where economy in construction is an object.

Nevertheless, the wish to produce an escapement possessing the valuable theoretical advantages of this system without being exposed to the acting parts wearing away, has originated some attempts to supply the pin anchor with jewels.

This has been done by taking the same lever and pallet-piece, merely having a little larger holes to fix ruby-pins into, in the shape of the locking-stone in the detent-spring of a chronometer. These pins can also be fastened by inserting them into a notch cut into the lever arm and shutting the notch by a slight pressure, so as to hold the jewel in its place. Diagram 5, A, shows both methods, the one on the first arm and the other on the second.

Diagram 5, B illustrates another plan on the same principle, approaching very nearly to the common construction. The pallet is made independent of the lever, and carries two jewels, presenting a thin edge to the lifting-planes on the wheel-teeth.

This construction is certainly not so frail and delicate as the former, but the pallet and lever must necessarily be much heavier.

Escapements of this kind have been made by some Swiss manufacturers, and according to Mr. J. F. Cole's description of his clock (*Horological Journal* I, p. 134), the escapement of this latter must be identical with it.

The lever escapement with the inclined planes partly on the anchor pallet and partly on the wheel-teeth is almost exclusively in use in the Swiss watches. It has the advantage of admitting the closest scaping and requiring the least possible amount of drop, because its teeth are hollowed out on their back part in order to secure sufficient freedom for the delivery-edge. The wheel of this escapement, with its little driving-planes on the ends of its teeth (club-teeth), is certainly much less exposed to injury, when falling into inexperienced hands, than the wheel with pointed teeth.

Most of the ordinary escapements of this kind are made with a circular pallet; that is, the pallet-arms of equal length, and the driving-planes at equal centre distances. There are the same reasons for speaking against this construction as already mentioned when treating of the escapement with the ratchet wheel. Still, the breadth of pallet-arms being considerably smaller, compared to those of a ratchet-wheel escapement, the incorrectness of a circular pallet to a club-wheel escapement is comparatively less, and reduces itself in proporti n to the part of the total lifting allotted to the wheel-teeth.

Diagram 7 represents a circular pallet with a club-wheel, of the proportions usually executed.

Diagram 8 shows a circular pallet with a club-wheel, the total lifting of which is divided equally between the pallet and wheel, for the reason above mentioned.

Diagram 9 illustrates an escapement with equidistant lockings and the total lifting distributed between pallet and wheel in the proportion in which it is usually done.

The escapement with the club-wheel, though superior in the economical use of the moving power, is still objectionable from another point of view. The inclined planes of the pallet-arm and wheel-tooth are so very little diverging, that with thick and glutinous oil there is much adhesion between them, which may produce under unfavorable circumstances a very disadvantageous influence on the performance of the watch.

CHAPTER VI.

THE ACTION OF FORK AND ROLLER.

THE parts which transfer the motion created by the action of the wheel and pallet to the balance, have also been constructed in a variety of different ways; and their action is commonly called the fork and roller action, because in almost all lever escapements the intervening lever is, at the extremity turned towards the balance, worked out into a notch, which gives it some resemblance to a fork. The roller in most of the lever escapements is a steel disc, carrying a pin to fit the notch in the fork. This pin is commonly made of a ruby, in order to diminish friction and give greater durability to the acting parts.

The fork and roller action can be divided into two distinct functions, in which the two parts act alternately the one upon the other. These functions are the lifting and the unlocking. In the lifting, the lever-fork impels the ruby-pin in the roller, being impelled itself by the lifting of the wheel-tooth on the pallet, which latter is solidly joined to the lever, so as to form but one piece with it. This impulsion of the wheel on the pallet, and the impulse of the fork on the roller arising from it, continues until the wheel-tooth drops from the edge of the driving-plane, which causes the corresponding tooth to fall against the locking face of the other pallet-arm. The pallet and fork are kept in that position while the balance makes its excursion to the same side. On its return, effectuated by the tension of the pendulum-spring, the ruby-pin has to perform the other function, in which it plays the active part, the function of unlocking. As soon as in this returning vibration the ruby-pin touches the fork, the latter (and also the pallet) follows the impulse a little way, thus withdrawing the locking-face against which the wheel-tooth is resting. The tooth, immediately after having left the edge of the locking-face, begins its lifting on the driving plane, which is transferred by the pallet and lever to the roller and balance; this lifting continues until the tooth has slidden across the driving-plane and dropped from the edge of it, after which the corresponding tooth rests against the locking face of the opposite pallet-arm. This play of the escapement is constantly repeated, so that the ruby-pin is driving a short way at each vibration, and is driven immediately afterward.

It is a peculiar feature of this part of the escapement, that it is quite out of action during the greater part of the vibration of the balance, and but a very little arc of the whole vibration keeps the roller in connexion with the fork. This circumstance on the one side constitutes the lever escapement a detached one, and endows it with all the valuable qualities of such escapements. But, on the other side, it produces a tendency to frequent disturbances in a portable time-keeper, which must be prevented by an arrangement of the parts, called the safety action.

It has already been mentioned in the description of the wheel and pallet action, that the locking-faces of the pallet cannot be made circular, or at least not concentric circles to the centre of the pallet, but must deviate from that circle so much as to produce a locking tendency, by which the pressure of the wheel-tooth on the locking face draws the pallet farther into the wheel. But this alone would not be sufficient to prevent the pallet leaving its state of rest in case of the watch being exposed to sudden external motions. The results of such uncontrolled motion of the pallet and lever would be that the lever would not present its fork to the ruby pin of the balance roller when returning from its excursion, but the pin would fall against the outside of the fork and the watch would stop immediately, requiring the aid of a watchmaker to put it right again. It is therefore of the greatest importance to secure continuous motion in watches with the lever escapement, by a careful safety action.

There is still another function which the lever performs in all the usual constructions. It has already been observed that the deviation of the locking faces from the concentric circle produces a tendency of the wheel to draw the pallet-arm towards its centre. This tendency would of course draw the pallet-arm in, until arrested by the circular rim of the wheel between the teeth; and this excess of drawing motion would occasion a great loss of power in unlocking, or even cause a butting of the ruby pin against some part of the lever not prepared for its reception. For this reason it is indispensable to reduce the motion of the lever and pallet to the amount required for the safe escapement of the wheel. This limitation is technically called the banking, and can be attained in different ways. In many watches, especially in the English ones, there are two upright pins planted into the plate at convenient distances from and on each side of the lever, near the fork end of it. (Banking pins.)

In the greater part of the Swiss lever watches the lever and wheel are sunk into the plate, and the fork end of the lever is banked against two projecting corners produced by the intersection of the sinks for the balance roller and the lever. In some watches we also find the banking-pins near the other end of the lever.

The banking of the lever, though indispensable for the good performance of the escapement, is at the same time a source of very disagreeable irregularities. When by a sudden circular motion of the watch in the plane of the balance (a very frequent occurrence when wearing the watch, or winding it up in a careless way), the vibration increases to more than two full turns, the impulse-pin strikes against the outside of the fork, which cannot yield, because it is leaning against the banking-pin or edge. By the violence of this percussion there is some danger of injury, not only to the ruby-pin, but also to the balance pivots, which are often bent or broken by the reaction. But more than that, all such cases are accompanied by a considerable acceleration of the rate of the watch, producing under unfavorable circumstances great differences in its timekeeping.

Of the three described modes, the banking between two pins is decidedly the best, provided the pins are not too thick and are as near the fork end as possible, thereby avoiding any essential part of the shock being communicated to the pallet axis. The elasticity of thin and hard pins proves to be a tolerable safeguard against the danger of any injury to the ruby-pin or balance pivots. But such pins are very easily bent when cleaning or repairing the watch, and then the banking will be too wide, or, still worse, too narrow, producing a want of freedom in the action of fork and roller, or in the safety action, or not allowing the wheel-teeth to drop freely from the driving planes.

The banking against solid corners of the sinks in the plate is not liable to such disturbances, and with such solid bankings the balance will not continue to strike against them so long as it does with the elastic banking-pins; but at the same time the danger of injury to the delicate parts of the escapement is greater. Besides, it is advisable to make these banking corners sharp, and not obtuse or flatted, as is often seen in such cases, where the banking was originally not wide enough. The consequence of such flattened corners is an adhesion between fork and corner when the parts are not perfectly clean, and this adhesion is an increase of resistance to the unlocking.

The worst system is that of banking the other extremity of the lever, between two pins or otherwise, because by this arrangement the lever transmits about double the banking shock to the pallet axis; and indeed, if a machine were wanted for the express purpose of breaking the anchor pivots, a better construction than this could not be devised, with a pair of thick pins and a strong unelastic lever.

By the preceding general remarks on the fork and roller action it will be seen that an investigation into the different constructions of these parts of the lever escapement must include their four different functions; the lifting, unlocking and safety action, and the banking.

DESCRIPTION OF SEVERAL FORK AND ROLLER ACTIONS.

1. *Rack Lever.*—The oldest method of transferring the impulse of the wheel and pallet to the balance was the rack lever. Its invention succeeded that of the application of the pendulum spring to the balance at a very short interval of time. The inventor of it was the Abbe Hautefeuille, who published it in 1722. His pallet is a recoiling one, though dead beat escapements existed long before that time. The balance axis is a pinion of six leaves, into which is pitched a toothed rack, fastened on the pallet arbor.

Though the employment of the rack lever deprives the escapement of the character of detachment, still, if combined with a dead beat wheel and pallet action, it has its decided advantages, and is even now resorted to in those constructions where extreme simplicity is desirable. It requires no safety action, because the rack and pinion cannot be disturbed in their connexion by any external motion. For the same reason the locking faces of the pallet can be made concentric circles to the centre of the pallet, thus avoiding the recoil and unlocking resistance arising from the draw. The rack lever also does nos require banking; and it is an advantage of this construction that it is free from all the inconveniences and risks connected with the safety action and banking. It is true the lever and pallet are compelled to follow the balance, even in its widest vibrations, and therefore the tooth on the locking face is running farther in than required, thus creating more friction; but this disadvantage is nearly made up by the absence of the draw and the unlocking resistance connected therewith.

The system of producing a large vibration of the balance by a rack and pinion is of very old date, and has been employed in other escapements, long before the lever escapement was known. (See Chapter I.)

The very easy and simple construction of the rack lever escapement is shown in Diagram 1

2. *Mudge's Escapement.*—The fork and roller action in Mudge's escapement shows a very curious complication, having the two prongs of the fork in different planes, the one a little lower than the other. It is evident that this arrangement has been made with a view of completing the safety action. We give the whole escapement of Mudge in its original shape (Diagram 1). *a* and *b* are the two prongs of the fork; *c* and *d* are two small impulse pieces on the balance-staff, the one over the other, and corresponding to the planes of the prongs. The acting edges of these two impulse pieces are rounded off so as to complete each other's form to that of a cylindrical impulse pin, and when the balance in its vibration comes to the point of intersection, the unlocking of the wheel is performed by one of the impulse pieces, while the other one receives its impulse immediately afterward.

The safety action of Mudge's escapement consists in a small disc of steel on the balance axis, with a shallow notch in it. A small and pointed piece of steel, *e*, is screwed upon

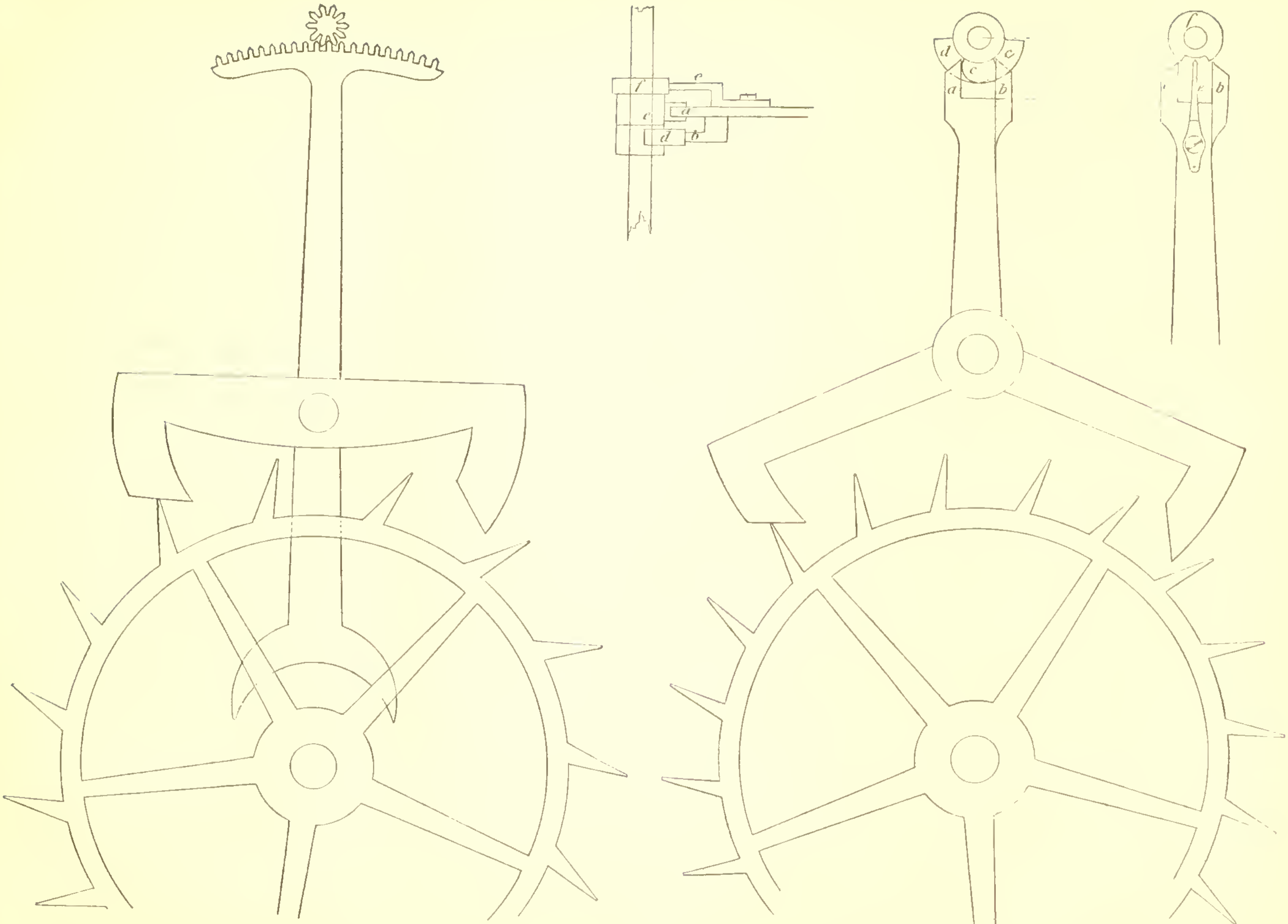


Diagram I.

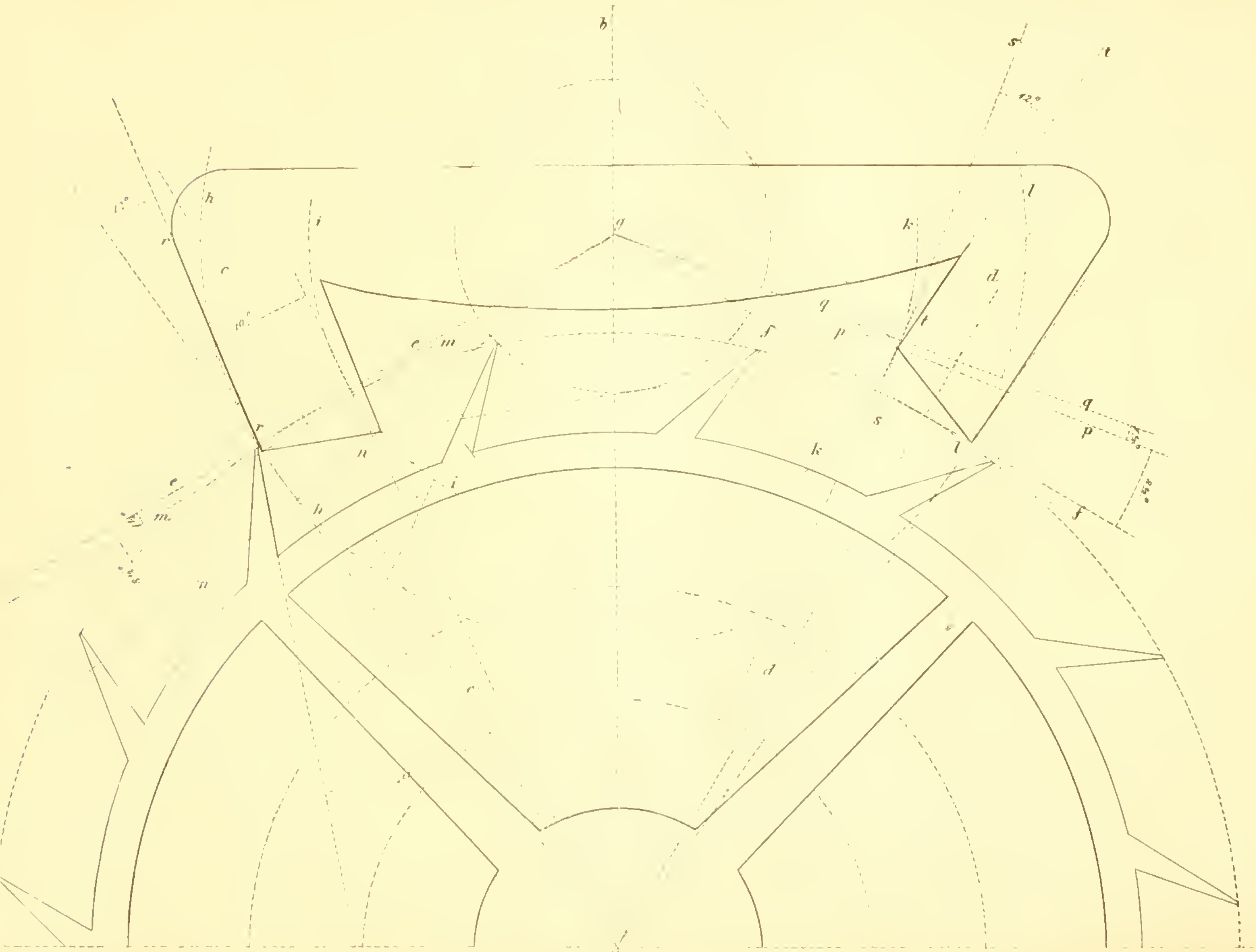


Diagram II.

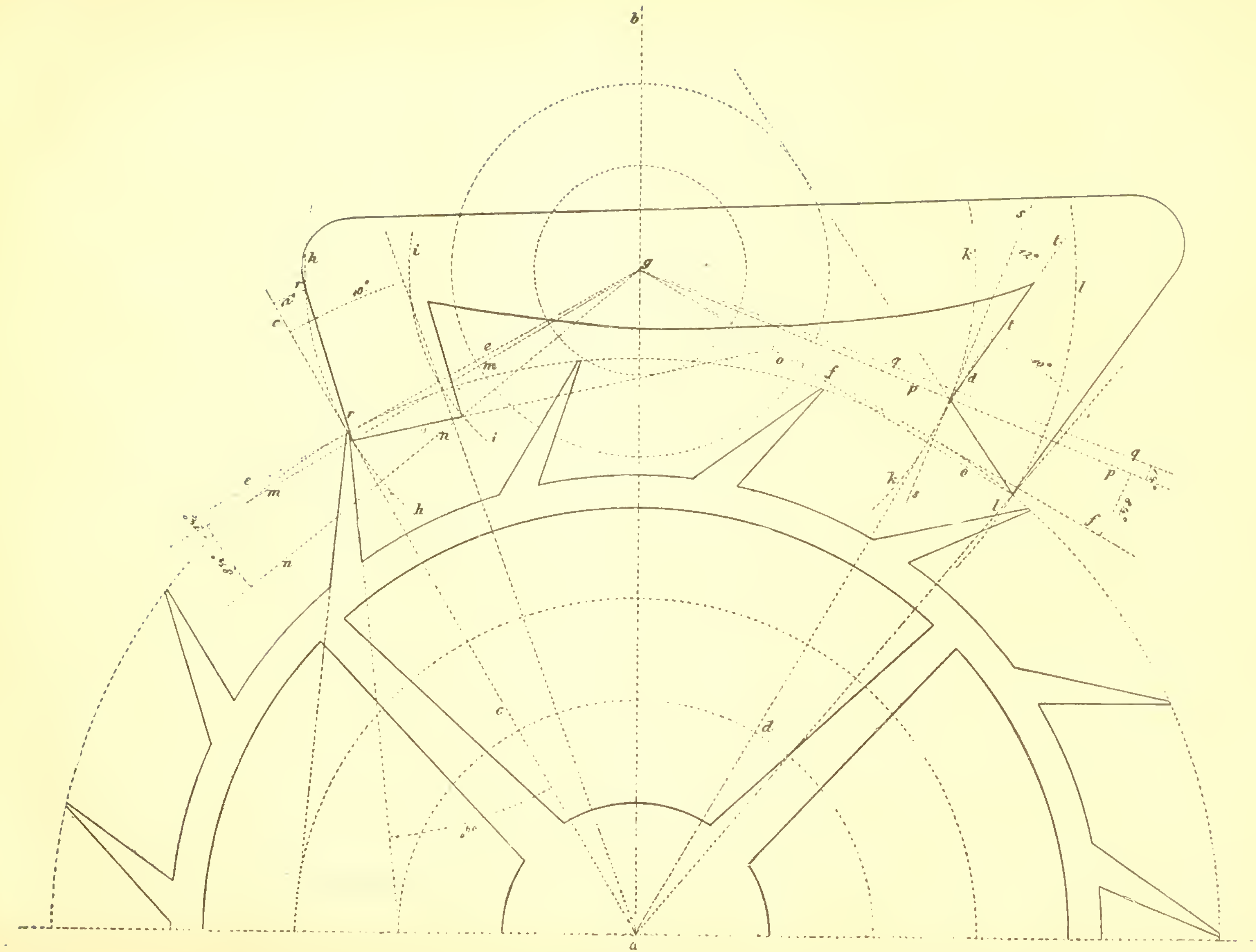


DIAGRAM III.

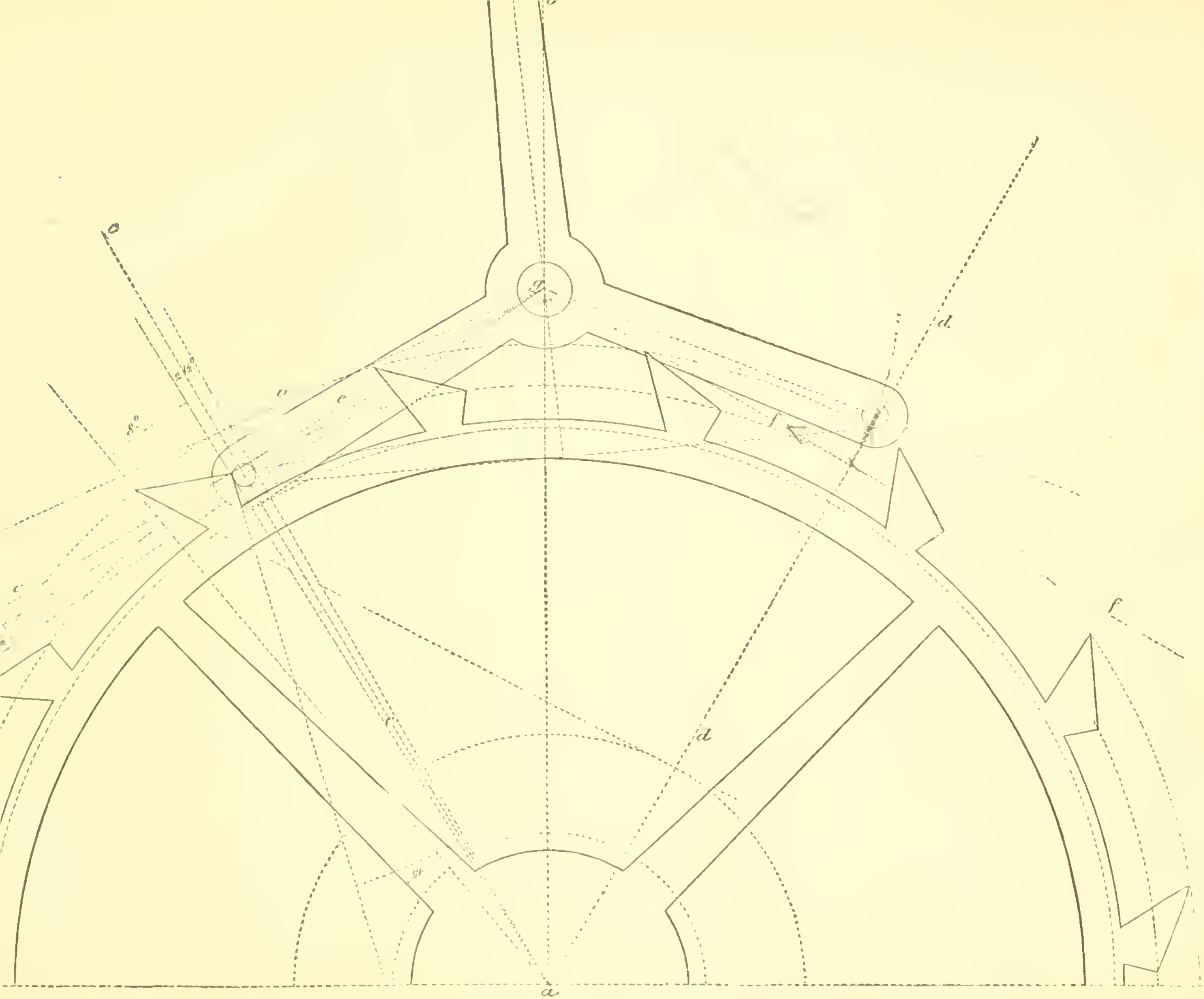


DIAGRAM IV.

the fork end of the lever in the same plane as the small disc or roller on the balance staff. When the balance in its vibration crosses the line of centres, the little index, *e*, passes through the notch in the roller and stands at a little distance from its circumference during the free vibration of the balance. This safety action is a very good one, but if not constructed with the greatest accuracy, there would be some danger of failing at those points where the impulse pieces leave the fork, because this latter has no horns. For this reason a complement to the safety action is given by the two impulse pieces each having a circular part, detaining the edge of the prong it has been actuated by from falling back by external disturbances during the period that the little safety roller is passing the centre line.

3. *The Table Roller.*—This is the name of a fork and roller action which has been employed more than any other. The greater part of the English and Swiss lever watches have the table roller. The roller is a disc of steel, carrying the impulse pin. The part of its circumference next the pin is filed out a little to form the passing hollow. The fork has on its extremity a notch to receive the impulse pin, which must pass through it freely and with a little shake. The safety action is effected in the English watches by an upright pin (guard pin) projecting from the surface of the lever very near the bottom of the fork, and corresponding to the passing hollow in the roller, which allows of its passing the centre line. During the free vibration of the balance the guard pin stands at a very little distance from the roller edge. The Swiss escapements have instead of the guard pin a projecting edge on the lever, near the bottom of the fork. (Diagram 9.)

To complete the safety action, which would be rather deficient at the time when the impulse pin leaves the fork, this latter has two horns projecting beyond the acting edges. The inner sides of these horns, or the sides turned toward the impulse pin, are formed by two eccentric circles. The impulse pin, when the lever is resting against the banking, passes these inner circles at a very little distance, thus preventing the fork from falling back to the other side until the guard pin is safely out of the passing hollow.

The edge of the roller must be carefully rounded and polished, to reduce friction to the smallest possible amount in those cases when the pallet may happen to leave its place of rest. The edge of the roller should not extend beyond the circle of the impulse pin more than is required for making a hollow deep enough for the passage of the guard pin. An unnecessarily large disc causes the guard pin to travel farther than the proper arc of escapement action in order to get safety hold, thereby causing a run of the wheel teeth on the locking faces. Diagram 9 shows the table roller in its different positions.

It may be here observed that the form of the impulse pin has been made very differently, though it is of the greatest importance to give it a good and proper shape. In many English watches we find full cylindrical pins, which is decidedly a very bad system. A cylindrical pin will not admit an advantageous transmission of movement; one consequence of this is a loss of power, both in the unlocking and in the lifting action. Besides, it is a source of other irregularities, the pin very often touching the bottom of the notch in certain positions of the watch, if the notch is not very deep and if the pivots of anchor and balance have much shake in their holes. In many Swiss watches the impulse pins have an elliptical form, which is much better than the cylindrical form. A cylindrical pin flattened down one-third of its diameter is very appropriate for economically transmitting the moving power without any loss by useless drop. In diagram 9 the flattened cylindrical pin is shown. In the same diagram the dotted lines (Figure B) illustrate the disadvantageous action of a full cylindrical pin. The disadvantage increases with the diameter of the pin.

The triangular form of the impulse pin is also very good, and admits, as well as the preceding, of the most profitable application of the moving force. Yet it may be observed that the flatted cylindrical pin is stronger, and consequently may be expected to oppose a greater resistance to the shocks it has to sustain, when striking violently against the bankings.

4. *The Double Roller Escapement.*—Under this designation is known an improved safety action which is now very much made use of in the better English and Swiss watches. The fork and roller action shows no difference to that of the table roller. For the safety action there is a steel disc or roller fitted on the lower part of the balance staff, and in corresponding height to it a pointed index piece or guard pin is screwed or fastened to the lower side of the lever on its fork end, and projecting toward the balance. The small disc is merely for the safety action, and has a hollow of sufficient size to allow the index to pass freely. It is strange enough that this method, originally employed by Mudge, has been laid aside for so long a time, and is now again resorted to and considered an improvement.

A comparison of the respective value of these two systems most in use speaks strongly in favor of the double roller. Diagram 9 of the table roller shows clearly that the arc and angle of intersection of the roller edge with the guard pin circle *k l* is much smaller than that of the impulse pin in the circle laid through the acting edges of the fork *e f*, the former being about four-fifths of the latter. This disproportion is of less consequence in escapements with large lifting arcs. But in our time the better horologists have aimed at giving more freedom and greater detachment to the vibrations of the balance by diminishing the lifting angles, and in such escapements, when made with the table roller, the intersection of the guard pin and roller edge would be so shallow that the least side shake of the balance and pallet pivots would make the detaining action a very doubtful one. This caused the return to Mudge's original plan. The double roller admits of a much greater arc of intersection for the safety action than that of the fork and roller. The double roller is not only preferable for giving a greater efficiency and soundness to the safety-action; it has still another and very important advantage in all those cases in which, by external influences, the pallet leaves its state of rest and the guard pin or index must be detained by the roller edge. Then the small roller will not experience so much friction on its circumference as the table roller. The effect of this friction will be still more diminished, because it is applied at a smaller distance from the balance center, and transmitted by a greater length of lever, compared to the table roller. For these reasons, the vibrations of the balance will be much less disturbed by the detaining action when the escapement is a double roller one.

5. *The Two-pin Lever.*—This is quite an original contrivance, and is doubtless, especially in its improved and jeweled form, the best fork and roller action that exists. It is based upon a separation of the unlocking and impulse functions, effecting both in a very advantageous way. The end of the lever is a fork with a wide notch, in which it receives the unlocking action by two upright pins fixed in the roller near its edge. Between these two pins there is a small notch in the circumference of the roller, which is to receive the impulse by an upright pin fixed into the lever very near the bottom of the fork. This pin at the same

time serves as guard pin, passing through the notch in the roller and resting at a very small distance from the roller edge during the free vibration. The distance of the two pins from each other embraces the whole arc of lifting of the roller, and by this arrangement the unlocking takes place in the line of centres, and consequently under the most favorable circumstances. Diagram 11 shows the position of the parts in their different functions.

The impulse action of the two-pin lever shows an inversion of the common principle, as the notch is in the roller instead of in the lever, and the lever carries the impulse pin, instead of the roller. The effect is the same as that of the common fork, except the mechanical advantage of the impulse obtained by the thinness of the pin (See Chapter XI.), and besides there is a complementary impulse, which is given by the prong of the fork opposite to that on which the unlocking has been performed, to the pin that did not unlock. This secondary impulsion, if the parts are properly made and pitched, avoids all loss of power arising out of the necessary drop, and thus we see in the two-pin lever system the greatest economy of moving power, both in the unlocking and impelling action.

The two-pin lever escapement was invented by George Savage, of London.

A fork and roller of this kind must be made very carefully and of correct proportions, and they would hardly do any service at all if constructed in such a careless way as the fork and roller parts of the lower kinds of lever watches are generally made. The above consideration of the superiority of this system will not, however, remove the apprehension that the acting parts, being not jeweled, might be worn out in a rather short time, or that those thin pins might be bent accidentally, when cleaning or repairing the watch. These circumstances created the desire to contrive a form of the two-pin lever possessing all the valuable qualities above mentioned, united with the durability and soundness of jeweled acting parts. This led to several improvements, and it seems that the inventor, George Savage, himself made a step in that direction, jeweling the notch by inserting two very small rubies in it and replacing the two unlocking pins in the roller by one broad ruby pin. Still the thin impulse pin was kept, with its liability to bending and to wear.

6. *The Solid Impulse Lever* removes this deficiency by making the impulse pin of a sharp triangular shape, worked out of the substance of the lever, or riveted into it This impulse pin is often replaced by a ruby pin of the same shape, while the notch of the roller is not jeweled. The unlocking is produced by the broad face of a triangular gold plug or ruby in the roller.

7. *The Jewel Roller Escapement* is another improvement on the two-pin lever. Its roller is made out of a solid stone, with a well-polished notch in it. The centre hole in the roller is large enough to receive a steel collet, on which it is fixed by a little shellac. This collet is fitted at a convenient height on the balance staff, and has a shoulder covering the greater part of the roller's lower surface, thus protecting it against injury. This collet carries near to its edge a broad and thin ruby pin for the unlocking. The impulse pin is the same as in the original escapement of Savage.

8. *The Spring Fork.*—This construction has been made for the purpose of avoiding all danger arising from violent banking, and all irregularities of rate resulting from the same. It is a common table roller or double roller escapement, with only the difference that the prongs of the fork are not made from the solid of the lever, but are replaced by two small springs fastened on the surface of the lever and projecting beyond its end. These projecting ends of the two springs form the prongs of the fork, and have the

common shape of these latter. They are kept at convenient distance from each other by two thin upright pins in the lever, near the end of it.

A lever watch with this spring fork may be subjected to sudden and violent movements without any fear of damage to the balance pivots or impulse pin, for if the vibration exceeds two full turns, the impulse pin will strike against the outside of one prong of the fork, which, by its elastic nature, yields to the shock and allows the impulse pin to pass. This play continues until the vibration has settled to a regular extent. Diagram 10 shows the spring fork and its action.

CHAPTER VII.

COMBINATION OF THE ACTIONS.

ANY one of all the fork and roller actions just described may be combined with any kind of wheel and pallet action before mentioned, thus forming a great variety of lever escapements. As the particular qualities of these different actions are not at all altered by any such combination, I have thought it best to refrain from enumerating all the varieties to be obtained, which would have been a very tedious proceeding, without any practical use. But before leaving the descriptive part of this treatise, I deem it right to say a word about the arrangement of the parts of the lever escapement.

The respective positions of the three pieces of the lever escapement, the wheel, anchor and balance, are not the same in all watches. There are two principal modes to be observed: The escapement in straight line, and the escapement in right angle. The latter is the usual plan resorted to in all English, and in the lower kinds of Swiss lever watches. The line from the wheel to the pallet centre makes a right angle, or nearly so, to the line from the centre of the pallet to that of the balance.

The Swiss manufacturers make their better qualities of lever watches with the escapement in straight line.

It might appear almost superfluous to state here that the performance of the escapement in either of these two arrangements, or in any other angle, is entirely the same, because, as is shown in the preceding chapters, the two actions of the lever escapement are perfectly independent mechanisms, and their nature cannot be altered by making them perform in any special angularity to each other. Therefore it is quite unjustifiable to consider a straight line escapement as an indispensable attribute of a first-rate lever watch; an opinion very much prevailing among the Swiss manufacturers and those connected with their manufacture.

The escapement at right angle allows a greater economy of space in the watch, and therefore is very appropriate for fusee watches. The straight line escapement, especially in ¾ plate watches, makes a better display of the acting parts.

Another apparent difference consists in the way of jeweling the pallet arms. This is done with *visible* or *covered* jewels. The covered jewels are fastened in a slit made in the middle of the substance of the pallet arm, horizontally or parallel to the surface of the pallet. The visible jewels are cut into the pallet vertically, (Diagram 6) so that the whole pallet-arm is a solid jewel. The Swiss manufacturers choose this plan for their first-class watches. The greater part of Swiss watches and all English lever watches are made with covered jewels. The action is in both cases the same, if the locking and lifting faces are properly made and if not, the one is as bad as the other. Therefore it is erroneous to consider the visible jewels as an essential and characteristic feature of a good lever watch, as many people in France and Switzerland do. The whole difference lies in the effect to the eye, and it cannot be denied that a well-made lever escapement with visible jewels is a very good-looking thing. Anyhow, the covered jewels are superior in point of solidity, because they can be fixed more firmly, owing to the large surfaces which they offer to the slit in the anchor; besides, those surfaces are rough, which makes the fastening more than efficient.

CHAPTER VIII.

DESCRIPTION OF TWO EXCELLENT ARRANGEMENTS OF THE DETACHED LEVER ESCAPEMENT.

As a sequel to the contents of the preceding chapters, we give here a description of the most advantageous constructions of complete detached lever escapements, for the purpose of serving as a base for the following chapters, explaining the respective proportions of the various parts of the escapement and the effects of alterations in the same.

The detached lever escapement, as it is made in the better English lever watches, is decidedly one of the best combinations. We give in Diagram 12 an illustration of an escapement of this kind, standing at right angles. The escape wheel with ratchet teeth is made of very good and hard hammered brass, and is usually polished. It would not be advisable to gild it, because by the common procedure of gilding the brass would lose its hardness and elasticity. But even when merely electro-gilt, the thin cover of precipitated gold cannot give as hard and durable a surface as that of carefully hammered brass; and besides, nobody can be sure that the different chemical ingredients employed by the gilders for the processes of gilding and brushing may not be retained to some extent by the gold in such a loose state, and produce a pernicious influence on the oil.

The pallet is made of steel, tempered, and has covered jewels. The lifting angle on the pallet varies from 8° to 12°.

In the better English lever escapements of later days, the lifting angle very seldom exceeds 10° from drop to drop, and this is the angle represented in all our diagrams. The lever is made of a thin, flat piece of steel, filed out on its sides merely to diminish its weight and give it a nice shape. The fork is the common fork of the double roller already described, and carries on its lower side an index for the safety action, fixed to it by a screw and a steady pin. The lever is joined to the pallet by a plain staff, forming the axis of both, and by a pin fitted in a hole drilled through the lever and pallet near to the extremity of one arm of the latter. This pin prevents any displacement of the parts, which would, of course, place the whole escapement out of going order.

The lever and index are tempered and the surfaces carefully polished, especially the acting parts of the fork.

The balance staff has a shoulder, on which the balance is fitted and rivited. On the lower part of the balance staff and next to the balance a steel disc or roller with a collet projecting towards the balance is fitted, carrying the impulse pin. This latter projects from the lower surface of the roller, is cylindrical, and flattened away one-third.

The small detaining roller is fitted on the balance staff, a little lower than the lower extremity of the impulse pin, just to agree with the height of the index on the lever.

The play of the lever is limited by two banking pins, whose place is near the fork end of the lever.

In full plate watches, the pallet staff and escape pinion have their pivot holes in the two plates, and may be of the full length allowed by the height of the frame. The balance is hung between two cocks on the upper and lower side of the upper plate.

In ¾ plate watches, the pallet staff and escape pinion must be brought under a small cock, to allow the balance above it the necessary freedom. They must then be very short, which is not advantageous, because the necessary side shake in the pivot holes has too much influence on the steadiness of the action. Therefore, it would be desirable to set the escapement in ¾ plate movements in straight line, because this arrangement allows a greater length of the escape pinion, while in full plate watches the escapement may be set in right angle just as well.

This escapement, as it is used in England, may serve as a fundamental type in all the following chapters treating of the drawing, execution and proportions of the lever escapement, and, in fact, all that can be said of this kind of lever escapement is in the same way more or less applicable to any other variety.

Another arrangement of the lever escapement seems well deserving of a short description here, because it has a very good tendency to facilitate the manufacturing process and to make the parts of the least possible weight, without any prejudice to their solidity. This escapement is devised by A. Lange, and is found in almost all lever watches manufactured in Glasshutte. (Saxony.) The escapement stands in straight line. The escape wheel is made of very hard hammered gold or aluminium-bronze, and has club teeth. The pallet and lever are but one piece, and of the same material as the wheel. The arm of the lever, opposite the fork end, which generally serves to establish the equipose, is suppressed here, and the fork arm made so thin as to be counterpoised by the weight of the pallet. The fork end has the usual form, and the guard pin is formed by a thin pin of hard gold or aluminium-bronze wire, fixed into a very small square hole next to the bottom of the notch in the fork, and bent in a right angle towards the balance. The pallet has its locking faces at equal centre distances and in equal angles.

The balance is compensated and hollowed out on both sides to allow a little more height for the pallet arbor. On the upper side, the hollow is not turned out close to the centre hole, thus leaving a pipe round this latter, to fit the pendulum collet on. The hole, in consequence of this, is rather long, but small; and the balance staff is but a straight arbor fitted tightly into this hole. This saves the trouble of turning a shoulder on both sides and riviting the balance upon it, besides leaving the possibility of little alterations in the height of the balance staff by driving this latter a trifle further in or out. Every practical man who knows by experience the vexation of a balance not being in proper height in an English watch, will agree that with this arrangement the defect is very easily removed, while in an English escapement another staff would be required. On the lower side of the balance the hollow is also not continued up to the centre hole, leaving a thicker part of the balance arm in convenient length from the centre to receive the impulse pin, which has a triangular form. By these means the roller which in the other lever escapements carries the impulse pin, is dispensed with, and consequently the dead weight of the balance staff and the manufacturing expenses diminished A small detaining roller completes the arrangement. The banking is effected by a pin projecting from the lower surface of the short or entrance arm, establishing at the same time the equipoise between the short and long pallet arm. This pin plays in a hole in the cock under the dial, or in the pillar plate, and the hole must be of just the size to allow the necessary freedom of escaping. This way of banking might be thought objectionable for the reasons mentioned in Chapter VI, but the lever in this escapement being very thin and elastic, there is hardly any danger for the pivots and impulse pin. Besides, it has the advantage of not being liable to derangement by careless workmen, for the banking pin in the pallet is so strong as not to be easily bent. Diagram 13 gives an illustration of Lange's lever escapement.

Mr. Lange has lately perfected the escapement in a way which deserves mention here. It is a natural defect of all lever escapements with inclined planes on the pallet, that during the lifting action, by the gradual movement of the pallet, the angle in which the lifting plane stands to the wheel tooth is altered in every movement of the action. The result of this alteration is an unequal distribution of the lifting along the length of the lifting plane. When we suppose this length divided into a certain number of equal parts, the angularity performed by one of these parts will not be equal to that produced by any of the other parts. This change of position of the lifting planes would be less objectionable if it were of the same nature for both arms of the pallet; but this is not the case. On the contrary, the angle of the lifting plane of the first arm increases continually during the lifting action, while that of the second arm is gradually diminishing. The intended angle of lifting is performed, nevertheless, but is not equally distributed within the length of the lifting plane. The inclination of the lifting plane on the first arm will be the least at the beginning of the lifting action, and that on the second arm will be greatest when the action begins.

This defect may be noticed by the circumstance that in well-made lever watches, in cases where the moving force is not sufficient, or its effect lessened by thickened oil and increased frictional resistance, the escapement has a tendency to set on the lifting face of the entrance arm when the pendulum spring is so adjusted that the balance stands right in the middle of action. To remove this defect, the adjustment of the pendulum spring must be slightly altered.

For better illustration, Diagram 13 shows an analytical sketch of the form which would be required for the two driving planes to produce an equal distribution of the lifting action For this purpose, the angle of lifting, as well as the breadth of pallet, is divided into a certain number of equal parts, and corresponding to the curvature of the wheel circle, the parts of the lifting angle are delineated by arcs described with the radius of the wheel, but from centres of increasing distance from the centre of the wheel. The points of intersection of the corresponding arcs indicate the form of the lifting faces, the first of which must be a convex curve, while the second must have a concave form.

It is difficult to execute such curved lifting faces practically, but the difficulties are happily surmounted, and it is a merit due to Mr. Lange to have invented and perfected this valuable improvement of the lever escapement.

CHAPTER IX.

DESCRIPTION OF SOME SPECIAL CONSTRUCTIONS ON DIFFERENT PRINCIPLES.

THE *Resilient lever escapement* is an invention of J. F. Cole, and may be considered as a successful solution of the problem of removing all the disagreeable eventualities connected with the banking. Its principle consists in limiting the locking-faces on the wheel or pallet to a very small extent, just sufficient for a sound locking. The continuation of this locking face stands at an angle to it, similar to the lifting angle, and this secondary lifting angle is for the purpose of leading the pallet back to its place of rest, if, in the case of banking, it has been pushed beyond its escaping arc. It is evident that an escapement of this kind needs no banking pins, because by the elastic recoil produced by the secondary lifting, the pallet and lever always return to the right place. Diagram 14, A and B illustrate the applications of the resilient principle most in use, the one with a ratchet wheel and the other with a club wheel.

However, I do not think that these two ways of applying the resilient system are the most commendable, because the inclined planes on the foresides of the teeth giving the resilient action, and the driving planes of the pallet, touch each other with very little divergence. This must result in a very detrimental influence upon the rate of a watch, because if the oil is getting thick and glutinous, every approach of these nearly coinciding planes will produce a strong adhesion, thereby augmenting the unlocking resistance. This disadvantage can be avoided by placing the resilient action in the pallet instead of the wheel teeth, in the way shown by Diagram 14 C, if a ratchet wheel is in question. With a club wheel, however, it would not be gaining anything, because the small inclined planes on the top of the wheel-teeth would nearly coincide with the resilient faces of the anchor, thus creating the same danger of adhesion.

Escapements with the lifting planes only on the wheel-teeth admit a very good resilient action if the foresides of their teeth are shaped in the way shown by Diagram 14, D.

Watches with a good resilient escapement may be brought to strike violently against the banking by strong motions of the watch, or by an excess of moving power, and still there will not be the slightest exposure to any injury on the pivots or impulse pin, nor will they show any essential deviation in their rate, after having banked for some time.

The repellent or anti-detached lever escapement of J. F. Cole is, as may be concluded by its name, quite a reversion of the ordinary principle. The pallet of this escapement has the same lifting planes as any other, but the locking faces are different. They have no draw, nor are they concentric circles to the pallet centre, so as to give a dead rest; they have on the contrary a small angularity, with a tendency to throw the pallet off, so that the escapement will run down if the balance be taken out. Instead of a fork, the lever has a thin pointed end, resting against the circumference of a jewel roller and giving the impulse to the balance, on the staff of which this roller is fixed by passing through a notch in the roller (Diagram 15) It is a great advantage of this escapement that it does not require any safety parts or banking, and consequently it is free of all the sources of error and failure connected therewith.

At first sight it causes a strange impression to see the greatest virtue of the lever escapement, the independence of its vibrations, thrown overboard so readily, with a view to perfecting it. Still, on close investigation, the idea is in many respects commendable, and well worth reflecting upon. The simplicity of this mechanism, and the removal of the danger of any external disturbance, are very important qualifications for its employment in pocket watches.

The unlocking without any resistance is also a very valuable economy of power, and must be esteemed so much the more, as in the detached lever escapement the unlocking resistance, which is one of the weak parts of it, cannot be removed.

The repellent lever escapement requires also a much smaller amount of drop than the detached lever escapement, with the same safety of action, because it does not require the teeth of the escape wheel being undercut, thereby allowing the back slope of the teeth to be cut in a direction to leave sufficient liberty to the entering pallet arm. The only objectionable point is the friction on the roller during the excursion of the balance. This friction is very similar to that in the duplex escapement, but in this latter it is not supposed an impediment to good performance. On the contrary, many watchmakers believe that a part of the superiority of the duplex escapement is chiefly due to this friction, which augments in the same rate as the moving force increases, and thus forms a kind of compensation of power. Apart from the fragility of the duplex escapement inseparable from its nature, it would be the most resorted to of all the escapements; and it seems that the repellent lever removes that natural defect. The chief object is to decide whether the friction of the repellent lever escapement is not greater than that of the duplex.

The roller of the repellent lever must certainly be much larger than the duplex roller, or the lifting angle would be disproportionally large. But in the repellent escapement the pressure of the lever end on the roller is but a small fraction of the force of the escape wheel, while the duplex wheel is pressing on its roller with the whole power transmitted by the train, only diminished by the greater diameter of the star wheel.

A simple calculation will be sufficient to show that a comparison between the friction of both these escapements does not turn to the disadvantage of the repellent lever.

To establish equal conditions for both, I will compare a duplex escapement, the impulse wheel of which has a diameter of 10 millimeters, and a repellent lever escapement with a wheel of the same size.

The star wheel of the duplex escapement of this size has a diameter of 13.0 m. and consequently, as the force is in the inverse ratio of the radius, the force with which the star tooth acts against the circumference of the roller is to the force of the upright teeth as 10-13, or supposing the force of the impulse wheel = 1, the pressure on the roller is $= \frac{10}{13} = 0.769$. The ruby roller in a duplex escapement of that size has a diameter of 0.77 m.

The repellent escapement with a wheel of 10 m. diameter will have a middle length of pallet arm = 2.885 m. Supposing now the length of lever arm to be 3.08 m. and the lifting intended on the balance roller 40°, the diameter of this latter would be 1.54 m. or the double of the roller in the before mentioned duplex escapement. The pressure of the lever end is now to be ascertained, and we suppose the angle of the locking faces to be 10°, which ought to be sufficient for the repulsion.

The pressure, being in the ratio of the sine of the angle, is in this case = sin. 10° = 0.1736 (the force of the wheel always supposed = 1). This amount is further diminished in the inverse ratio of the length of the pallet arm to the length of the lever arm. This latter being 2.885 m. and the former 3.08 m., the pressure of the lever end acting on the circumference of the roller is $= \frac{0.1736 \quad 2.885}{3.08} = 0.162$.

Thus the pressure on the duplex roller is to that on the repellent roller as 0.769 to 0.162.

The friction on both these rollers can be supposed in the ratio of the squares of the diameters, and as the roller of the repellent scapement is double the size of that of the duplex, is as 1-4. Therefore the frictional coefficient of the repellent roller must be multiplied by 4 to give the whole amount of comparative friction, $0.162 \times 4 = 0.648$ This number, compared to that of the duplex, shows clearly that the repellent lever of the proportions supposed in this case is by no means at a disadvantage in point of friction.

I have thought it not amiss to give this calculation here, because the comparison without it would be very uncertain, and might easily lead the student to underrate this invention.

When we consider, finally, that the repellent lever escapement has not so much loss of power by the diminished drop of both the wheel and pallet action and that of lever and roller, and besides no loss of power by unlocking resistence, it may be considered as a rival to the detached lever escapement, even without taking into consideration the constructive advantage, and soundness of action.

Comparing it to the duplex, and leaving the settled question of friction aside, the repellent lever has the advantage of giving an impulse at each vibration; and though the transmission of the impulse in the direct way, as we have it in the duplex, be superior to that by the diagonal driving planes and intervening lever, the circumstance that the duplex impulse requires for the safety of its action a drop of about 10° before falling on the duplex pallet may be considered to make up for that deficiency.

By omitting the fork and guard pin, the lever of this escapement may be constructed of very little weight, but it is necessary to establish carefully an exact equipoise of the pallet and lever, lest the escapement might go entirely out of action.

There is one drawback, however, to this escapement. Though it will never set on the lifting, when properly made and kept in good order, it will not go on by itself when the notch in the roller stands in the centre line and the lever end is lying on the right or left side of the roller. This happens very easily, when the watch has gone down. In such cases, the watch requires, as well as the duplex watch, a small motion to make the balance vibrate.

Diagram 15 B shows a pin anchor escapement upon the repellent principle.

CHAPTER X.

INSTRUCTIONS FOR DRAWING CORRECT ESCAPEMENTS.

The correct way to draw the escapement is a very important desideratum, especially for those who would like to give a solid and rational base to their endeavors in this part of watchmaking, because, for reasons best known to themselves, practical working men do not like to undergo the trouble of developing the sizes and angles they require by mathematical calculations. For these persons the graphic way is the most convenient when any uncommon construction or size of escapement is required, while for problems of frequent occurrence they may find it more convenient to go by the tables which will be found in Chapter XII

For making a good and accurate drawing of a lever escapement it is necessary to adopt a rather large scale, because the lines of very small angles, as for instance 1° or 1½°, would nearly coincide if not drawn up to a certain length. Most of the before-mentioned diagrams are made with a radius of the escape wheel = 100 m., which is convenient for drawing, and for the reduction of sizes.

THE LEVER ESCAPEMENT WITH THE RATCHET WHEEL.

Draw a circle with a radius of 100 m. in which the points of the wheel teeth are lying, and trace the line of centres *a b*. From this line set out to each side 30° with the aid of the protractor, and draw radii *c* and *d* to embrace this angle.

These 60° form the escaping angle of the wheel, and correspond to 2½ spaces between the teeth. (The wheel is always supposed to have 15 teeth, though it might have any other number, and as the whole circumference of a circle is = 360°, the space between two teeth is $= \frac{360°}{15} = 24°$). Through the two points of locking found by the intersection of the radii *c* and *d* with the circumference of the wheel, draw rectangular lines *e* and *f* to the radii, which of course are tangents to the circle, that is, lines touching the circumference but in one point. The point *g*, in which the two tangents are crossing each other, falls into the centre line, and is the centre of motion for the pallet. The next thing to do is to mark the breadth of the pallet arms. This would in theory be equal to half the space between two teeth, or taking the space as 1-15 of the circumference of the wheel, 12° from the wheel centre. But in practice it is impossible to give this breadth to the arms, because no wheel can be made mathematically true in its division, and every moving part of the watch must have for the free movement of its pivots a certain shake. The points of the teeth, too, cannot be made perfectly sharp edges, nor can the slope on the back part of the teeth be hollowed out for the free passage of the delivery edge of the pallet.

For all these reasons, a sufficient quantity of drop is indispensable for the good and safe action of the escapement, and it will prove a good proportion to employ for this purpose 2° of the wheel's circumference, thus leaving but 10° of the 12° for the breadth of pallet arm.

If a circular pallet is required (Diagram 2), these 10° must be marked as 5° on each side of the radii *c d*. For forming an escapement with equidistant lockings (Diagram 3), the 10° must be applied to the right side of both the radii *c* and *d*.

Through the points in which the lines of these angles intersect the circumference of the wheel, the circles *h* and *i*, *k* and *l*, must be traced from the pallet centre, giving the theoretical outlines of the pallet arms.

To form the driving planes, it is necessary to indi cate the angles of locking and lifting. Of the whole angle of movement (which, in all these drawings, we suppose to be 10°, though it might be more or less than that), $1\frac{1}{2}°$ must be reckoned for the locking, and the remaining $8\frac{1}{2}°$ serve for the driving action. Supposing the tooth on the outside of the pallet to be on the locking (which for the sake of uniformity will be so in all the drawings), the $1\frac{1}{2}°$ of the locking angle, as well as the $8\frac{1}{2}°$ of the lifting angle, must be taken towards the wheel centre on the entrance side. The lines *m* and *n* are drawn so as to embrace these angles. Corresponding to this position of the first pallet-arm, the delivery edge of the other arm must be in the periphery of the wheel, where the circle *l* is intersecting it. A line *o* must be drawn from the pallet centre to this point, and outside from the tangent *f* the lines *p* and *q* embracing the angles of $8\frac{1}{2}$ and $1\frac{1}{2}°$. The points where the lines *m* and *n*, *o* and *p*, are crossing the circles *h* and *i*, *k* and *l*, when joined by straight lines, give the direction of the driving planes of the pallet.

For the purpose of creating the draw, it is necessary to make the locking faces of the pallet deviate from the theoretical circles *h* and *k*, which would only give a dead rest. Therefore a straight line *r* from the outer edge of the entrance arm must be drawn, standing at an angle of 12° to the tangent of the circle *h*, which tangent is in this case identical with the radius *c*. The same angle of draw being required for the locking face of the other arm, a tangent *s* must be laid to the circle *k* in the inner edge of the driving plane on this arm. The locking face is drawn by a straight line *t*, in the angle of 12° to the tangent, from the inner edge of the driving plane.

To promote this drawing action and diminish friction on the lockings, it is necessary to give an inclination to the foreside of the teeth. An angle of about 24° to the radius will be what is required for this purpose. The sloped back-face of the tooth must be made so as to give a solid tooth, and the lower part of the tooth may have any shape whatever. The only thing required is to have the extremity of the tooth thin enough to enable the pallet to escape freely. For saving the trouble of marking these angles for each tooth separately, the following method is very convenient: Prolong the straight line forming the foreside of one tooth, and draw a circle from the centre of the wheel, to which this line is a tangent. Then draw from all the points of teeth straight lines touching this circle in but one point, and these are the foresides of the teeth and all in the same angle to the radial direction. The back lines of the teeth may be drawn in the same way.

The delivery faces of the pallet arms are made parallel lines to the locking faces, and the rest of the outline of the pallet, which has nothing to do with the action, requires but a convenient shape.

THE ESCAPEMENT WITH THE CLUB TEETH.

Diagram 7 shows a club tooth escapement with circular pallet. Draw a circle with a radius of 100 m., in which the fore edges of the teeth are lying, and a line of centres *a b*, on each side of which set out 30° as before; then trace the radii *c* and *d* and the tangents *e* and *f*. From the crossing point of these tangents, *g*, which must be in the line of centres *a b*, draw a line *v* in an angle of 4½° to one of the tangents, outside of the circle. These 4½° form the lifting angle for the inclined planes of the wheel teeth, and the remainder of the total lifting angle of 8½° is assigned with 4° to the pallet. The outer edges of the teeth lie in a circle drawn through the crossing point of the lines *v* and *c*.

The 12°, or half the space between two teeth after a subtraction of 1½° of drop (Chapter V shows why with the club wheel a smaller quantity of drop is sufficient), equal to 10½°, must be divided between the breadth of tooth and that of the pallet arm. Corresponding to their respective lifting angles, they might be made, the tooth 5½° and the pallet arm 5°. But this proportion is not obligatory, and might be altered in any direction.

The 5° of the breadth of pallet arm must be set out with 2½° on each side of the radii *c* and *d* and the circles *h* and *i*, *k* and *l* drawn, as already described.

The angle of total movement = 10°, leaves after the subtraction of 1½° of locking, a total lifting of 8½°, divided so between wheel and pallet that the former performs 4½8 and the latter 4°.

At first, the locking angle = 1½°, must be marked inward of the tangent *e* by the line *m*, and then the 4° of lifting by the line *n*. In the same way these two angles are marked on the other pallet arm outside the line *o*, drawn through the crossing point of the circle *l* with the circumference of the wheel. The driving planes are drawn in the way already described.

The locking faces of the pallet are made with the same drawing angle and in the same way as formerly mentioned when speaking of the ratchet wheel. The foreside of the teeth, too, is made with the angle of 24° to the radius.

To form the inclined planes of the teeth, set out the breadth of tooth = 5½°, to the left of the radius *c*; take the resulting size with the compass and mark it on each tooth to the left side. By drawing straight lines between the outer and the fore edges the inclined planes on the teeth are defined. The back of the teeth must be hollowed out in a suitable way for the free passage of the delivery edge of the pallet, and the shape of the pallet made in the usual manner. (Diagram 7.)

The pallet with equidistant lockings does not require this particular distribution of the lifting action, and in most cases the lifting angle is so divided that only about one-third of the total lifting is performed by the wheel teeth.

In this case, the lifting will be 2½° on the wheel and 6° on the pallet, and the respective breadths will be, for the tooth 3½° and for the pallet arm 7°.

Draw the line *v* at an angle of 2½° to the tangent *e*, and the circle from the wheel centre passing through the crossing point of the line *v* and the radius *c* is the circle of the outer edges. Mark the inclined planes and fore sides of teeth in the way already described.

Mark the 7° for the pallet arm to the right side of the two radii *c* and *d*, set out the locking angle = 1½° and the lifting angle of the pallet = 6°, and draw the circles and lines as already described. (Diagram 8.)

Diagram 6 is an illustration of the circular pallet with the club wheel and the usual repartition of the lifting angle for better comparison of this way of executing with the one indicated by Diagram 7.

THE PIN ANCHOR—DIAGRAM 4.

Draw a circle of 100 m radius for the fore edges of the teeth, trace the line of centres, *a b*, and mark out on each side of it 30°; draw the radii *c* and *d* and the tangents *e* and *f*, as before. Mark on each side of one of the radii 1¼°, double which, 2½°, is the diameter of the pin. The tooth outside being supposed to be on the locking, the locking angle of 1½° must be marked inside the circle by the line *m*, and the circle of the pin drawn from the crossing point of this line with the radius *e*. This done, the half of the space of 24° between two teeth must be divided. After subtraction of 2½° for the thickness of the pin and 1½° for the drop, the remainder = 8° is the breadth of the tooth. Mark this angle on the circumference of the wheel to the left of the pin, and divide the wheel to give teeth in equal spaces and of equal breadth.

The total angle of lifting is composed of two parts: the lifting on the inner half of the pin, and that on the inclined planes of the wheel teeth. The thickness of the pin supposed to be equal to 2½° of the wheel, a lifting angle of about 2° on the anchor results from it, and the whole lifting angle being appointed = 8½°, the remaining 6½° must be performed by the wheel teeth. Mark this angle outside of the tangent *e* by the line *v*, and lay a circle from the centre of the wheel through the point where this line crosses the radius *e*. This circle embraces the outer edges of the teeth. Draw the inclined plane of one tooth, prolong the line of it, trace a circle to which this line is a tangent, and draw through all the fore edges of the teeth tangents to that circle, which give the inclined planes all in the same angle.

The pin of the entrance arm standing at the locking, the pin of the other arm must accordingly be outside of the circle of the outer edges of the teeth. To mark this pin draw an arc from the crossing point of the radius *d* with the tangent *f* and set out half the thickness of the pin = 1¼° on this arc, just outside of the outer circle of the wheel. This gives the centre of the pin.

The foresides of the wheel teeth must now be drawn with the angles of draw = 15°, which is done in the way already indicated.

The back lines of the teeth are made parallel to the locking face of the second following tooth, to give the anchor pins freedom to enter into the space. The parallelism of the two lines mentioned is not essential, but it affords a convenience in cutting the wheel. To finish the drawing, give a suitable shape to the anchor arms.

THE JEWELED PIN ANCHOR.

This escapement is to be drawn in a very similar way, with the only exception that in this case the edge of the ruby pin can be made sufficiently thin as to produce no supplementary lifting angle, as the round pins in the pin anchor do. (Diagram 5, A and B).

Draw the radii *c* and *d* and the tangents *e* and *f*, and inside of one tangent the locking angle = 1½°, and outside of it the lifting angle = 8½° by the lines *m* and *n*. Draw a circle through the crossing point of the line *m* and the radius *c*. Then set out 10° to the left of the locking radius for the breadth of tooth, leaving 2° for the drop. Draw the inclined planes of the teeth, give the foresides of the teeth the drawing angle of 15°, and shape the reverse in the way already explained. Trace the locking faces of the pallet jewels in a drawing angle of 10°, and shape the rest of the pallet and jewels appropriately. (In Figure B visible jewels are supposed, though they might be made as well covered in the usual way.)

THE RESILIENT LEVER ESCAPEMENT.

The drawing of the resilient escapement, after what has been said, requires no further explanation. (Diagram 14, A—D.)

THE REPELLENT LEVER ESCAPEMENT.

For drawing the repellent escapement trace the line of centres *a b*, and the radii *c* and *d*, in angles of 30° on each side of it. Mark the breadth of pallet arm = 10½° on the right side of the radii *c* and *d*, and draw the circles *h, i, k,* and *l*. Mark the angle of locking = 2½° and that of lifting = 8½° inside the tangent *e* and outside of the tangent *f*, and draw the driving planes of the pallet. Then mark an angle of 10° for the repulsion, outside of the tangent of circle *h* and inside of that of the circle *k*, and shape the pallet as usual (Diagram 15). The foresides of the teeth may be radial and the back slope just sufficient to give a solid tooth.

THE TABLE ROLLER—DIAGRAM 9.

Draw the line of centres, *a b*, and to the right and left side of it the lines *c* and *d*, at an angle of 5°, the sum of these angles being 10°, the total movement of pallet and lever which we suppose in all the diagrams. Mark on each of these lines the acting length of the lever by the points *e* and *f*, representing the edges of the notch in the fork. Take one-third of this length as radius and draw two arcs from the points *e* and *f*. These two arcs cross in the line of centres, and their crossing point *g* is the centre of the balance. From this centre *g* draw two straight lines to the points *e* and *f*, which in this case embrace an angle of 30°, the lifting angle of the roller. The distance between the centre *g* and the points *e* and *f* is the acting radius of the roller, and the outer edges of the ruby pin must coincide with a circle drawn through these points. The pin has commonly a breadth of about 5°, measured from the pallet centre. Mark this size with 2½° on each side of the centre line, and draw the form of the ruby pin, by which the size of the notch in the fork is given, which must have a sufficient width to allow the necessary shake to the pin.

The horns of the fork must be made parts of circles, so as to admit free passage of the ruby pin when it has gone through the arc of intersection. To provide for any want of accuracy in the execution, this freedom is generally made to increase a little towards the ends of the horns, and for that reason the centres of these circles are not adopted in the points of intersection of the lines *e* and *f* with the circle drawn out of the centre *a*, through the balance centre *g*, but a trifle towards this centre on the same circle. See Diagram 9, points *h* and *i*).

The edge of the disc still remains, and the passing hollow in it. The diameter of the disc must be taken as small as can be, just to hold the ruby pin with solidity after the passing hollow has been made. This latter can be a little smaller than the breadth of the ruby pin, and the guard pin must be put in the lever so as to give the lever 1° of play between the banking pin and the roller edge.

All the rest is merely a matter of form and elegance, keeping in view the practical importance of making the parts as light as soundness and solidity of action will permit.

THE DOUBLE ROLLER—DIAGRAM 10.

The drawing of the fork, roller and ruby pin of the angles and respective lengths are the same as those of the table roller When all this is done, draw the circle of the small roller for the safety action. The diameter of this roller varies in the greater part of escapements between $\frac{2}{3}$ and $\frac{1}{2}$ of the acting size of the impulse roller. Diagram 10 A shows the first-mentioned proportion, while in B the safety roller is half the size of the impulse circle The length of the index piece is such as to have 1° of play to the roller edge when the lever is resting against the banking.

The passing hollow in the impulse roller is no more required, but that in the small roller must be larger than that in the table roller, corresponding to the greater arc of intersection in this safety action, which in A = 51° and in B = 76°.

In consequence of this larger arc performed by the safety action, the horns of the fork in a double roller escapement must be longer than those of a table roller escapement.

THE TWO PIN ESCAPEMENT.

Draw the same lines and angles as before described. A circle drawn through the points *e* and *f* from the centre *g* represents the impulse roller. In the middle of the arc *e f* draw the impulse pin and the notch to receive this pin, with a shake of 1 to 1½°.

At the distance of 4-5 of the radius of the impulse roller draw the circle for the two unlocking pins, which must be set so that their outsides are exactly embraced by the arc of lifting, here supposed to be 30°. The acting (inner) sides of the fork coincide with the prolongation of the lines *c* and *d*. The fork has no horns, because in cases where the escapement would tend to unlock, it would not be possible that the prong of the fork, standing outside, could fall as much inward as to pass or to butt against the corresponding unlocking pin. The bottom of the notch in the fork must be made a little slanting from its middle towards the prongs, for the purpose of procuring sufficient strength for the hole in which the impulse pin is fitted, without making the notch in the fork too shallow.

The drawing of the impulse pin and jewel roller escapement, as well as that of the spring fork, requires no further explanation, because in fundamental principles they are quite identical with those constructions the drawing of which has already been described.

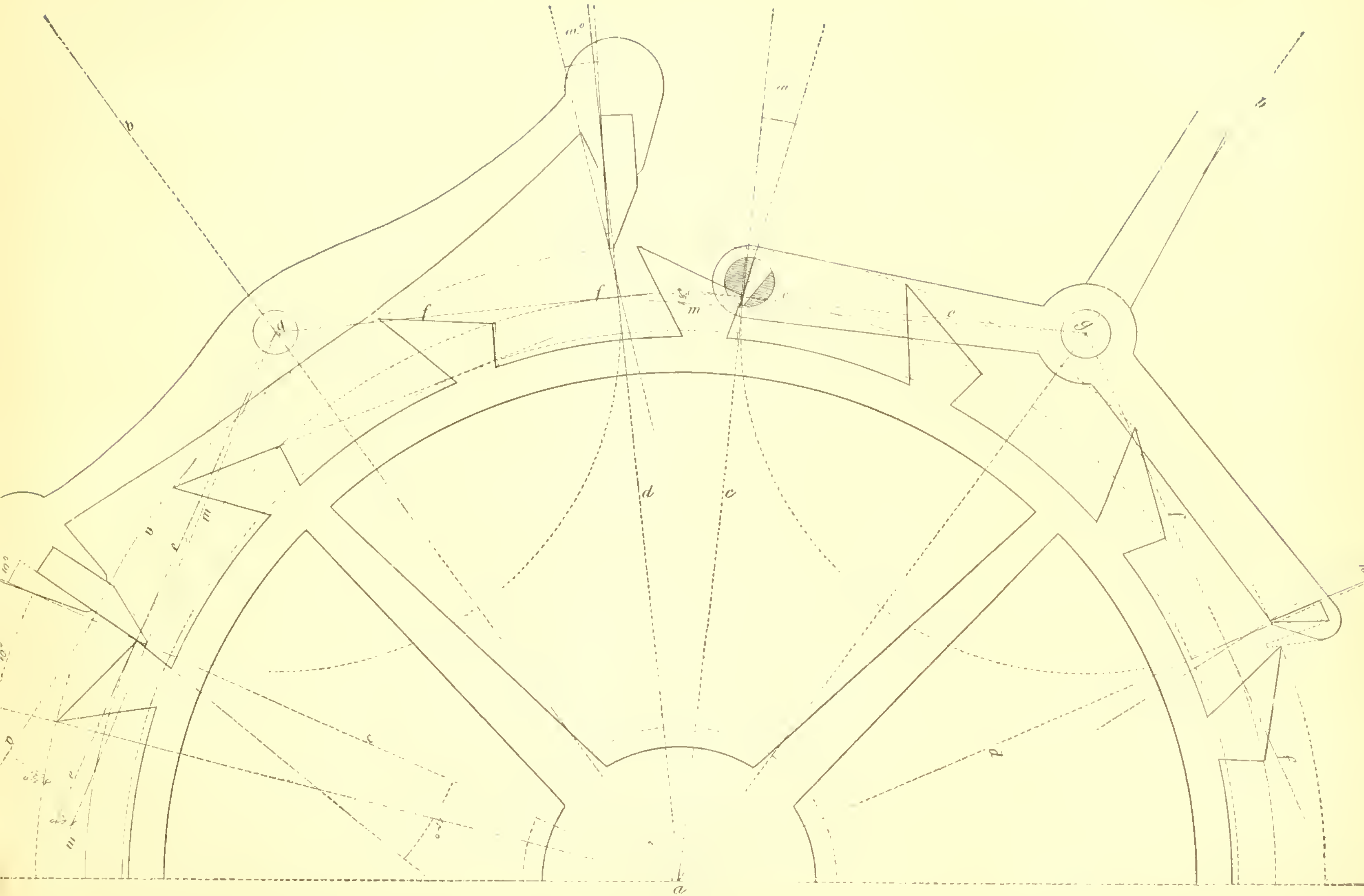


DIAGRAM V.

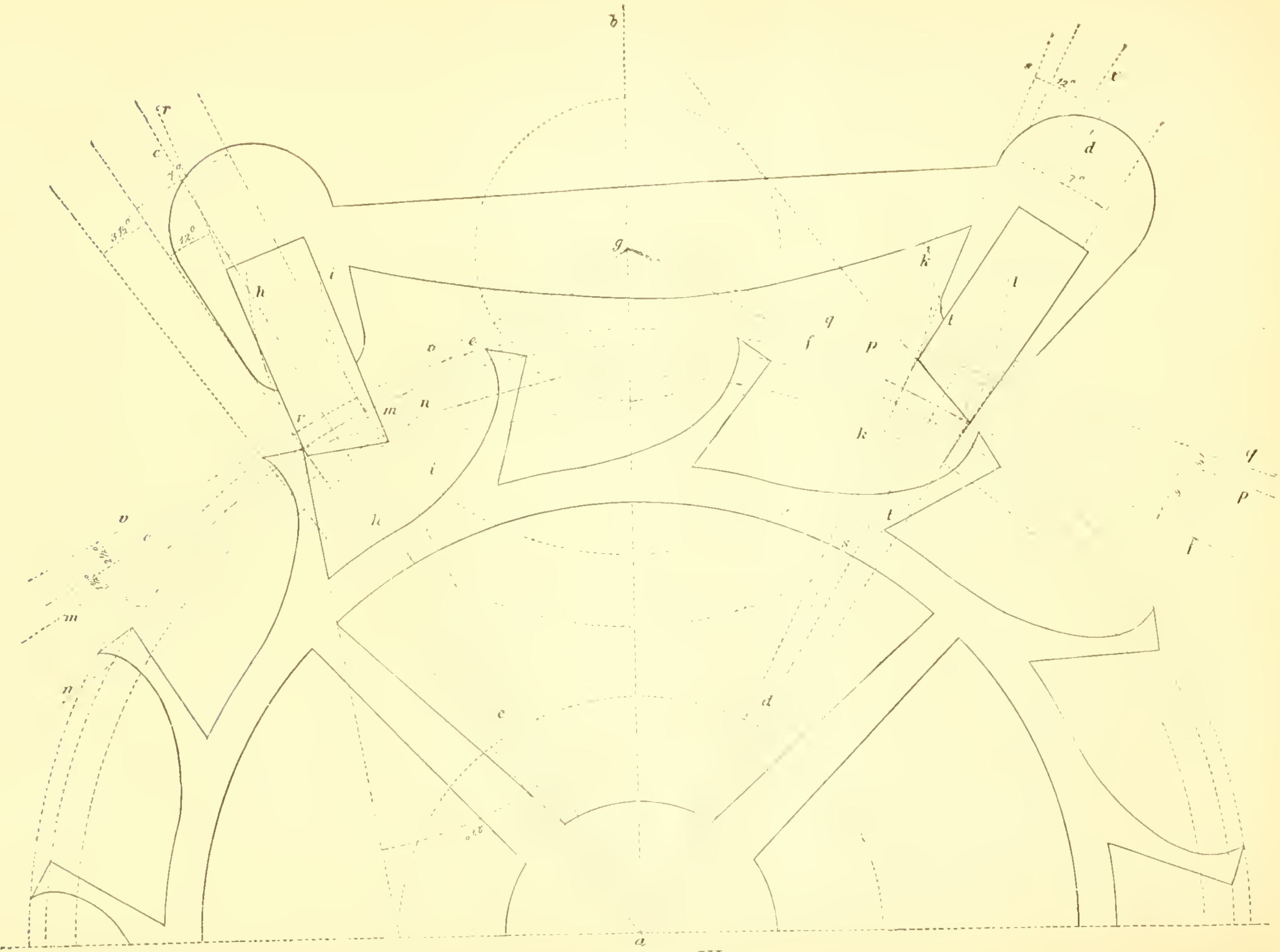


Diagram VI.

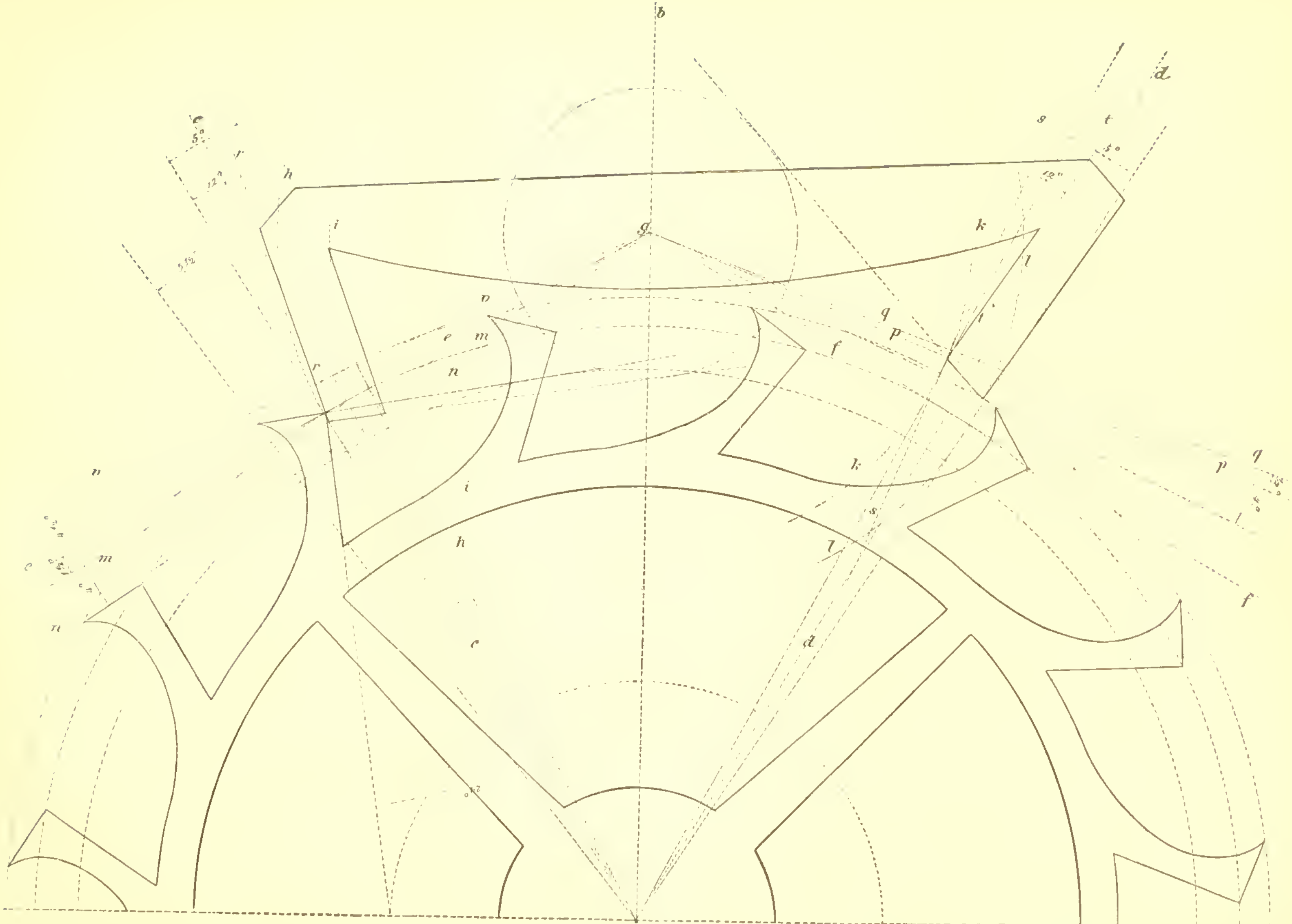


DIAGRAM VII.

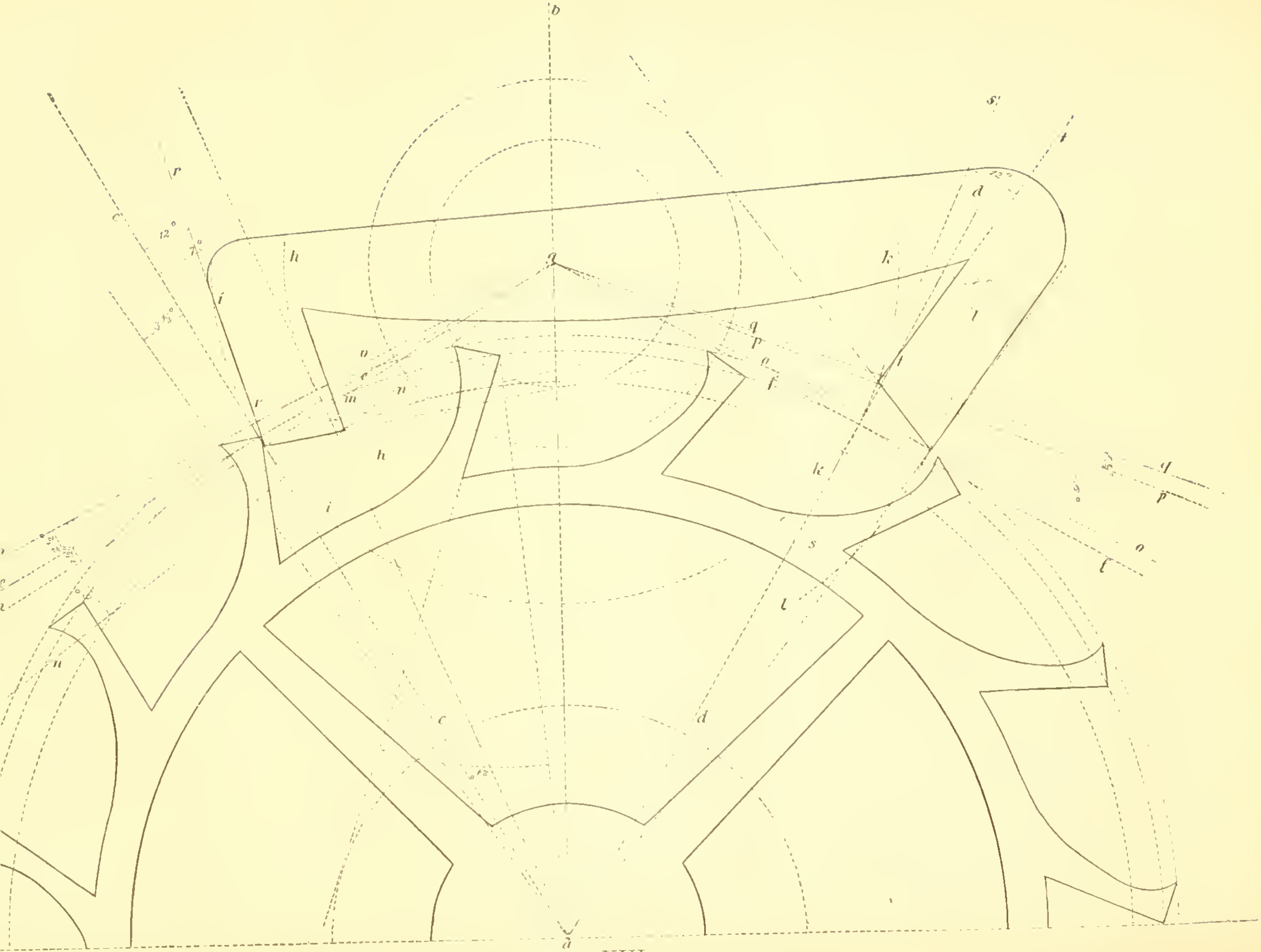


DIAGRAM VIII.

CHAPTER XI.

ON THE PROPORTIONS OF THE PARTS OF THE LEVER ESCAPEMENT, AND THE EFFECTS OF VARIATIONS IN THESE PROPORTIONS.

ONE of the most important essentials to a thorough knowledge of the detached lever escapement is to ascertain the best respective proportions of its parts. The nature of this escapement, being composed of two distinctly separate actions, admits a greater variety of proportions than any other. This circumstance accounts for the fact that an indefinite number of very divergent opinions on this matter are to be fonnd among horologists, and it must be well understood that many of the questions bearing in this direction cannot be answered absolutely and positively, because the different proportions of the moving force to the weight and diameter of the balance and to the required speed of its vibrations, as well as the amount of care which can be bestowed on the execution of the escapement, and many other considerations, essentially influence the matter. Nevertheless, we must try to establish at least some general principles which will, if discreetly adhered to, secure a good performance of the escapement under common circumstances, and be a safeguard against extremes in any direction.

To begin with the wheel, the number of its teeth is generally fifteen. This number, however, is by no means essential, nor need it be an odd number, as many are inclined to suppose. We should see many wheels with other numbers if the greater part of lever watches were not required to show seconds, and for this purpose the number of 15, being contained without remainder in 60, is the most convenient. Therefore, and because a wheel of a different number is a very rare occurrence, in all the diagrams, calculations and tables this number of teeth will be supposed. Any increase of this number without alteration of the number of teeth embraced by the pallet would diminish the angle of the wheel scaped over, and *vice versa*, as shown by the following table:*

Number of wheel teeth.	Arc of wheel scaped over.	Number of wheel teeth.	Arc of wheel scaped over.
10	90°	16	56° 15′
11	81° 48′	17	52° 55′
12	75°	18	50°
13	69° 13′	19	47° 22′
14	64° 16′	20	45°
15	60°		

The number of wheel teeth embraced by the pallet, though universally three, is also not a mechanical necessity, and with perfect analogy to the anchor of Graham's dead beat escapement, which generally embraces from six to twelve teeth, the pallet of the detached lever escapement might just as well be made to scape over two, or four, or even more teeth. Therefore the effects of variation in this particular must be examined, to ascertain which number is the best.

For better illustration of these effects, Diagram 16 shows with one and the same wheel of fifteen teeth four different pallets, the entrance arm of all of which is locking at the same tooth. The first pallet, scaping over two teeth, is drawn with all its auxiliaries and outlines marked with the number 2. The next one, scaping over three teeth, is marked 3 in all its lines. The following, over four teeth,

*The pallet is supposed to embrace 2½ spaces of teeth.

has the number 4, and the last one, embracing five teeth, shows the number 5 on all lines belonging to it.

It will be very easily perceived by this combination that every increase of the number of teeth scaped over makes the driving planes more diverging from the tangent, or from the direction in which the force of the wheel acts, and more approaching to the direction of the radius—the direction which would absolutely oppose any action of the wheel. It will further be seen that the arc of locking becomes more extended and that the pallet arms and driving planes grow longer with every increase of the number of teeth scaped over.

It might appear that the increase of length of the pallet arms would be a mechanical advantage—an increase of power; but such it really is not, because the effect of it, the work performed by the lever and the force employed to this purpose are the same.

On the other side, there are considerable mechanical disadvantages connected with a pallet of large dimensions. The greater length of the driving planes, together with the unfavorable diagonal direction of the same, are attended with greater friction, and what is the worst of all, the unlocking resistance increases in the ratio of the squares of centre distance, while the gain of power, if such could be obtained by the longer arms of the pallet, would only be in the ratio of the simple centre distance.

It must also not be overlooked that a pallet scaping over five teeth would necessarily be a rather heavy object, the inertia of which would require to be overcome at every beat of the escapement, and that an escapement with such a pallet would require more space than could be well afforded in a watch.

If, therefore, a pallet scaping over five or four teeth does not work with any mechanical advantage, and better conditions can be obtained by scaping over a smaller number of teeth, it might be asked whether three teeth would not be also objectionable to a certain degree, and whether we had not better make all our pallets scape over two teeth.

This is a point which must be thoroughly examined, and the same considerations decided here in favor of the usual system will apply to many other particulars in the lever escapement, so that it is preferable to treat this matter more amply. When it is asked what number of teeth scaped over will be the best system, and whether three are preferable, or more, or less, it must be considered that there are reasons for and against any of the two extremes. We have already mentioned the considerations that make a pallet scaping over more than three teeth appear objectionable. The pallet scaping over two teeth is certainly not so heavy as that over a larger number of teeth; the driving planes, being less divergent from the direction of the wheel's action, admit a more perfect transmission of power; the action on the driving planes is shorter, but more energetic, and occasions less friction; the locking arc and unlocking resistance is reduced to the smallest amount possible. Still, there are considerations obliging us to keep within certain limits also on this point.

A glance at Diagram 16 shows that the arcs of motion, though the angle be the same for all the four pallets, exhibit a great difference, arising from the different lengths of pallet arms or radii. The lengths of these arcs are, measured from the diagram:

For the pallet over			two teeth,	. . .	5.6 m.
"	"	"	" three "	. . .	9.9 "
"	"	"	" four "	. . .	15.8 "
"	"	"	" five "	. . .	24.0 "

It cannot be doubted that the real effect of all these lifting movements will be a little less than it was intended to be, because in reality the shake which must be granted for the freedom of the pivots in their holes will produce by the reaction on the inclined planes a tendency of the acting parts to take the widest distance possible. This loss in the mechanical effect is of much more consequence than it is usually esteemed to be. Therefore it will be advisable to deduce its extent by a little calculation. For common size escapement pivots a shake in the holes of 0.015 m. is an absolute necessity. This shake of the escape pinion and the pallet axis make together an increase of the pitched distance of 0.03 m., when both parts are taken in an unfavorable direction, as will be mostly the case when the parts are in action.

The size of the wheel in this diagram is to that of a common size escape wheel about as 30 : 1. Consequently the effect of this increase of distance will be for a wheel of the size in the diagram = 0.9 m.

When we compare now the difference of 0.9 m. with the total extent of the arc of movement in the pallet over two teeth = 5.6 m. (See the table), we shall find that it is a loss of about 1-6, or 16 per cent. of the intended total lifting effect.

Escapements with a pallet scaping over three and more teeth, requiring exactly the same conditions for the freedom of their pivots, suffer of course under the same loss of mechanical effect, but not so much to their disadvantage, for the alteration of 0.9 m. in the pitched distance is but 9 per cent. of the whole arc of movement of the pallet over three teeth. The pallet over four teeth has under the same circumstances but a loss of 6 per cent., and that over five teeth loses only 3.7 per cent. of the total amount of intended motion, by the same shake of the pivots.

This diminution of the lifting effect is, however, not so detrimental as the loss on the locking. The extent of the locking arc when measured on the drawing is only 0.9 m. with the pallet scaping over two teeth, and consequently the whole locking action would be annihilated by the indispensable shake of the parts, and the necessity would urge a greater angle of locking. Thus the gain obtained on one side would be lost on the other.

In all this, we have merely spoken of carefully sized pivot holes and carefully pitched pallets, and it must be perceived by the examples given that for a pallet over two teeth the slightest excess of shake in the holes, or the smallest deviation from the true pitch, would immediately produce the greatest irregularities in the action of the escapement, while the same defect would be of little consequence to a pallet over three teeth. In short, the pallet over three teeth is preferable, because those over more than three teeth work under mechanical disadvantages, further augmented by thickening oil, etc., and because the pallet over two teeth requires a greater accuracy of execution than could be afforded under common circumstances.

The angle of lifting on the pallet is another very important point, on which, nevertheless, opinions are very different. We see escapements with lifting angles varying from 6° to 12°, and even more, and the question which of these angles is the best is a very natural one.

Diagram 17 is intended to illustrate the effects of different lifting angles. One and the same pallet is represented with an angle of total movement of 6° from drop to drop, and with an angle of 15°. For the lifting of 6° a locking angle of 1° has been adopted, while that of 15° shows a locking angle of 1½°. The lines belonging particularly to the angle of 6° are marked 1, and those referring to the angle of 15° are marked 2.

The effects produced by these two extreme angularities are the following:

The driving planes increase in length with the lifting angle, and at the same time they become more divergent from the direction in which the wheel acts. In both cases the whole power of the wheel is acting, but as the pallet with the longer arc is made to go through a wider distance, it is quite plain that the action at each point of this distance cannot have the same energy, according to the great rule of mechanics that the force is in the inverse ratio to the velocity or to the distance to be passed over. Besides, the friction on these longer and more diagonal driving planes is also a disadvantage.

On the other hand, the reasons already mentioned will apply here to prevent the construction of pallets with too short arcs. A pallet with 8° of total movement will require the utmost restriction of the locking angle, else this latter would form too great a part of the whole movement; in consequence of which, this pallet would necessitate a very exact pitching and a most careful sizing of the pivot holes, because the least imperfection in these points would make the lockings unsafe and occasion considerable loss in the real effect of the lifting. We find the long arcs of movement in all the inferior classes of watches, and with good reason, especially when there are no jewel holes for the escape pinion and pallet axis, in which case a greater shake must be granted, because the brass holes cannot, for durability, be made so short or be rounded off, as a jewel hole may be. Short arcs, down to 8°, are employed only in the very best and most carefully constructed watches.

For escapements with the table roller it is not advisable to employ a pallet moving less than 10°, because the arc of intersection for the safety action is then too small to admit a perfect performance.

The shape of the teeth may also be made an object of consideration. An alteration of this shape would be possible by making the acting faces less inclined, and altering the back slopes accordingly. This would produce a shape similar to that in Mudge's escapement (See Diagram 1), and would be desirable by diminishing the drop which must necessarily be given to a ratchet wheel to make the delivery edges of the pallet pass freely the back slope of the tooth. But a very serious objection to such shape of teeth is that the friction on the locking would be considerably increased, because there would not be the point of the tooth, but a part of the acting face of it, lying against the locking face. The drawing action of the pallet would also be annihilated by approaching the acting face of the teeth to the radial direction. For this reason it is not advisable to make the inclination of the teeth less than 24° to the radius.

The length of the teeth, if the lifting angle of the pallet is not an uncommonly large one, may be 1-10 of the wheel's diameter. Any excess of length, especially with a ratchet wheel, would be of no use, and would put the durability of the wheel in danger.

With respect to the form of the club teeth, the same considerations demand a sufficient inclination of their foresides. The objection of any loss of power by too much drop does not apply to the club wheel, because the possibility of hollowing the back part of the tooth allows as close scaping as possible. The small inclined planes on the club teeth should be of such angle that the lifting on the pallet would be performed first, and that of the wheel tooth take place afterwards, at the delivery edge. When the total lifting angle is divided so that its greatest part is assigned to the wheel, without giving at the same time more breadth to the teeth, the result will be that the lifting of the wheel tooth is performed first, by the inclined plane of the tooth at the entrance edge, which is not so favorable as in the first method.

The wheel teeth of the pin anchor, and similar constructions, are bound, as to the forms of their fore faces, to the necessary drawing angle. The back part must be undercut to allow free passage to the pin during the slight recoil produced by the drawing angle at the moment of unlocking. The lifting faces of the teeth may be made in different ways. Some of these escapements have straight lifting faces, some of them curves, although there seems no reason for adopting this latter system, as the lifting angle of this kind of wheels, different from all other kinds, is regular from beginning to end, so that any part of the length of the lifting face shows the same lifting effect as any other part of the same length, which cannot be said of the club wheel, and less still of the ratchet wheel. In fact, if it were of any importance to give to a ratchet or club wheel escapement this regularity of lifting, the lifting faces of the two arms would require to be curved, and differently curved, too, the one on the entrance arm convex, and the other concave. This complication has not been thought essential for regularity of performance; but when the pin anchor affords by its nature this correct progression of the lifting, we can see no reason for destroying it. Therefore the straight line seems to be the best shape for the lifting faces of the wheel teeth in the pin anchor escapement.

The length of the lever, in its proportion to the length of the pallet arms, exhibits the greatest variation of all the proportions in the lever escapement. This is explained by the fact that the fork and roller action is entirely independent of the action of the wheel and pallet. The length of lever may be in any proportion to the diameter of the wheel, or, which is the same, to the length of the pallet arms, without prejudice to the mechanical effect. We find escapements with levers whose acting length is more than three times the length of the pallet arm. Swiss manufacturers have gone very far indeed in that direction, for the purpose, probably, of making a fine display of the escapement, this idea evidently prevailing in all their manufactures. But to the practical horologist this is but a secondary consideration, and we must ask in the first place, what are the effects of increased length of the lever on the performance of the escapement?

The answer to this question is very similar to those already given when speaking of the proportions of the pallet. Any increased length of lever will require a greater radius of impulse, or a greater distance of the impulse pin from the balance centre, if the angle of lifting remains the same, and consequently the arc of intersection will be longer, and the friction of the acting parts must increase in the same ratio. The force transmitted both in the unlocking and the impulse action is the same whether the lever be long or short, provided the angles performed and the proportions of lever length and impulse radius remain the same in both cases, and the only difference consists in the greater breadth of intersection and the increased friction connected with the long lever.

These considerations would lead to employing as short levers as possible; but it must be observed here that the diminution of the intended effect of the movement by the necessary side shake in the pivot holes must be taken notice of, because the loss arising from this circumstance, though an absolute quantity, is in very different proportion to the extent of the distance to be performed by the fork and roller action. Therefore it is advisable not to go too far in either direction, and it may be esteemed a good proportion to make the lever not so long as to allow its arbor to stand beyond the circumference of the balance.

One consequence of the short lever in all three-fourths plate watches will be that the pallet arbor must be made very short and the escape pinion too, if the escapement is not set in straight line; but the advantages of diminished friction outweigh this minor defect of construction so much that we see all the better lever watches of our day, and the English lever watches without exception, with short levers of about 0.55 to 0.6 of the diameter of wheel.

The angle of lifting on the roller depends entirely upon the proportion of the length of the lever to the centre distance of the impulse pin (impulse radius), and the angle produced at the roller is in the inverse ratio of these lengths to the angle performed by the lever.

If, for instance, the length of the lever be 4.2 m. and its angle of movement 10° and the angle of lifting on the roller is intended to be 30°, the acting length or radius of impulse will be:

$$\frac{4.2 \text{ m. } 10}{30} = 1.4 \text{ m.}$$

For a lifting angle of 35° it would be:

$$\frac{4.2 \text{ m. } 10}{35} = 1.2 \text{ m.}$$

and for a lifting angle of 40°:

$$\frac{4.2 \text{ m. } 10}{40} = 1.05 \text{ m.}$$

When we try to ascertain which lifting angle is best suited to a good performance of a lever escapement, we must in the first place examine the effects produced by changing the extent of this angle. The consequence of a large lifting angle is a longer arc of intersection, attended with increased friction and diminished energy of impulse at each point of its path, because the same force must be spent to perform a longer course. The consequences of a small lifting angle are the unfavorable extent of the loss of movement by shake of the parts, and the greater influence of alterations of intended effect by improper pitching or wearing out of the pivot holes and pivots. All these considerations are nearly the same as before mentioned, and their result is that any excess in both these directions ought to be avoided, but that within certain limits, and especially in escapements made and pitched in a very careful way, the performance of the smaller angle ought to be preferred for the greater detachment of the vibrations of the balance afforded by it.

But there is still another reason against the large angle of lifting. This is the very unfavorable action of the unlocking, which takes place at the two extremes of the lifting arc. It is evident that this action will be the easiest when performed as near the centre-line as can be, and will cause more loss of power the farther it takes place from this line. This loss of power finds no compensation in any other part of such construction, and consequently it should be avoided as much as possible.

One circumstance is also of great influence upon the decision of this question, and it must be indicated here, though falling beyond the reach intended for this treatise. The unlocking action has to be performed by the returning vibration of the balance, and this vibration is effected by the tension of the pendulum spring. This tension, supposing all other circumstances to be the same, will be stronger if the unlocking takes place farther from the centre line, and will diminish the nearer it comes to that line, on which there is no tension at all. In such cases, when the balance is small and not heavy enough, the vibrations slow and the pendulum spring weak, the balance will stand a bad chance of overcoming the unlocking resistance, especially when, for obtaining a large vibration, a mainspring of proportionately great strength is applied to the watch Under such circumstances the escapement will have a tendency to set on the lockings and not to go on, except by an external motion of the watch. Therefore, in all cases in which these proportions are not established with the utmost accuracy, and the greatest care in making and pitching the escapement cannot be bestowed, it is not advisable to give a lifting angle of less than 30°.

The respective proportions between the lifting angle at the pallet and at the roller are also not dictated by any general rules of mechanics, and escapements might possibly be constructed with a small angle at the pallet and a large one at the roller, and *vice versa*. It is also by no means essential that the angle at the roller be such that the angle at the pallet be contained in it without any fraction. This proportion is quite arbitrary, and will not influence the mechanical effect. Nevertheless, as the considerations which make us choose certain angles as the best suited under certain given circumstances are the same for both the angles in question, it is very unlikely that anybody, except in some particular case, should execute a lever escapement with a very small angle for one and a very large angle for the other action.

The size or breadth of the impulse pin is also a matter deserving some attention. Many people prefer a broad pin for the impulse, to facilitate the unlocking action. This is quite correct, because a broad pin requires a wide notch in the fork, and consequently brings the unlocking action nearer to the line of centres, which is the most favorable place for it.

But it must not be overlooked that every gain on this side is a loss on the side of the impulse action, because in the same proportion as the unlocking is approaching the centre line, the impelling action is removing from it. Therefore the solidity of the pin itself must be the principal consideration, and it may be called a suitable dimension if a flatted cylindrical pin has a breadth of 0.06 to 0.07 of the diameter of the escape wheel.

The above mentioned circumstances have led to the ingenious invention of the two-pin lever by George Savage, the essence of which, as it has been already indicated in Chapter VI, is a complete separation of impulse and unlocking, by which the possibility is attained of employing a thin pin for the former and a broad one, or two pins at suitable distance from each other, for the latter.

For escapements with the two-pin lever the smallest possible angles of lifting will be practicable, because it offers the most favorable conditions for both the actions, and the most economical transmission of moving force.

With respect to the two-pin lever especially, the proportion of the unlocking radius to the radius of impulse is subject to variations, which in all other fork and roller actions are impossible by their nature. It seems to be of great advantage for an easy unlocking to place the unlocking pins as near the centre of the balance as possible, because by forming a shorter lever and acting upon a greater length of the fork lever, the unlocking resistance may be better overcome. But this would be a very great mistake, because in the first place it would require a much larger arc of balance motion for the unlocking, and besides the considerable difference of speed with which the unlocking pins would move, compared to the outer edge of the roller, would have the effect that the notch would have nearly passed the impulse pin before the unlocking was completely over. To prevent the butting of these parts, a much wider notch would then be required, and the drop arising from it would consume more than the power saved on the unlocking. The best plan, therefore, seems to be to plant the unlocking pins as near the edge of the roller as can be, and four-fifths of the radius of the roller may be considered a very good proportion of the unlocking radius of the two-pin lever.

The size of the detaining roller is of no great consequence for the action of the lever escapement, because the parts belonging to the safety action are not acting parts, as all the rest of the escapement, but on the contrary are quite out of action during the common, regular performance of the escapement, and in well made escapements are acting only in very exceptional cases, when by some external influence an irregularity in the functions of wheel and pallet happens. Their action is also of very short duration, because the next vibration must necessarily re-establish the regular state of things. For the soundness of the safety action it is sufficient to give the detaining roller just the size of the impulse circle, so as to make its angle of intersection equal to that of the impulse pin. But in those exceptional cases where the detaining roller plays the active part it is intended for, it is important to diminish the friction arising out of the pressure of the index or guard pin against the circumference of the roller to the smallest amount possible, which, supposing the surfaces of the parts to be polished very smoothly, can only be effected by giving the roller the smallest size permitted without prejudice to the soundness of the safety action. In good watches with double roller escapements, the detaining roller is about half the size of the circle of impulse, which size admits still a very efficacious safety action, with an arc of intersection amounting under the other circumstances supposed here to about 80°.

The length to be given to the horns of the fork is not the same for all escapements; it is dependent on the angle of intersection of the safety action, and on the form and breadth of the impulse pin. Thus, the fork of the table roller escapement may be made with much shorter horns than another one with a double roller, and this latter will require a greater length of horns in the same proportion in which the diameter of the safety roller is made smaller compared to the circle of impulse. A very broad impulse pin, the foreside of which is made to agree with the impulse circle, admits the total admission of the horns, and we would see escapements of this construction more frequently if, besides the unfavorable action of lifting caused by such breadth of the impulse pin (See the paragraph treating of the size of the impulse pin), there were not an objection to be raised against it because it restrains the total space allowed for the vibration of the balance to less than two full turns, thus creating a tendency to banking. This objection, however, being removed by the resilient escapement, the broad pin and the fork without horns have been employed for escapements of this class.

This chapter is one of the most important of this treatise. I am perfectly aware that the reader who takes it in hand with the hope of finding here brief and definite instructions how to make the parts of a good lever escapement in certain proportions will be much disappointed. The nature of this matter, however, would not permit such a course, and it would be indeed something like arrogance on my part if I could have expected to dictate to the horological world certain proportions as the only ones fit for a good lever escapement. Such a way of proceeding would have been very convenient, but this is not the purpose for which this chapter is written. It is my object to stimulate thought by its contents, in order that each one may find the proportions best suited to the kind of work he is making.

The assistance in practical execution which might have been expected here will be furnished by the following chapter, after having chosen, according to the contents of the present one, the most appropriate lifting angles and proportions for the given circumstances.

CHAPTER XII.

TABLES OF PROPORTIONS.

THE following tables have been prepared for the express purpose of facilitating the construction of correct lever escapements upon a truly scientific basis, and without experiments or testing instruments, with the aid of the universal measuring system mentioned in Chapter II, which will be completely described and explained in Chapter XVI.

The tables are arranged, not only to provide for the common procedure of making an escapement to a wheel of a given size and pitching it afterwards, but they may also be applied in those cases in which any part of the escapement must be replaced to fit exactly to the other parts and to the pitched distance. I think tables of this kind have not previously existed, and I hope they will prove very useful to the practical workman, who does not like making calculations.

The tables refer only to escapements with wheels of 15 teeth and pallets scaping over 3 teeth, because deviations from these proportions are of very rare occurrence, and the enumeration of all such exceptional cases would extremely complicate the tables, without being of any real use. In all cases in which it might be desirable to construct an escapement, or to replace parts of one, having any deviation from these generally adopted suppositions, the type of calculation given to each table will indicate the shortest way to calculate the required proportions, while for those who are not accustomed or not inclined to calculations, the explanations given in Chapter X will be sufficient to enable them to make a correct drawing of the escapement to be made, and the proportions taken from a drawing of the proposed size will afford all the accuracy that could be wished for, attainable by human hands.

The tables of proportions for the wheel and pallet action are made under the supposition of three different angles of total movement: 8°, 10° and 12°. For the first case, a locking angle of 1° is adopted, while those of the two others are 1½°, so that after subtraction of the locking angle there remains a real lifting of 7°, 8½° and 10½°. For any lifting angle between these three, if it should be required, the numbers will be easily found by interpolation, as their progression is merely an arithmetical one.

EXPLANATION OF THE DIFFERENT COLUMNS IN TABLES I AND II.

It must be mentioned in the first place that these tables purposely give the diameters of all circles and not their radii, though the latter are the real acting lengths. This has been found preferable with a view of making the tables more handy and convenient to the practical workman, who always measures the diameters, because the radii cannot be measured in a direct way.

The second column contains the sizes of the wheels, when measured. These sizes do not exactly equal the diameter of the wheel, because the odd number of teeth does not admit of measuring two oppesite teeth, but always one tooth and the space opposite to it. This makes a difference equal to the height of arc of an angle of 24° from the wheel centre, amounting to 0.0109 or 1-100 of the diameter of the wheel, and thus a wheel measuring 9.9 m. has a real diameter of 10 m. For all cases where wheels must be made to fit to a certain given centre distance or pallet, I have thought it useful to take this difference into consideration.

TABLE I. Circular Pallet. Ratchet Wheel.

1	2	3	4	5	6	7	8	9	10
Diameter of wheel.		Circles of pallet.		Lifting circles for *total* angle of pallet movement.			Height of segment.	Breadth of pallet arm.	Distance of centres.
Real 1.0	Measured 0.99	Outer 0.6647	Inner 0.4901	8° 0.211	10° 0.248	12° 0.292	0.502	0.0873	0.5774
5.0	4.95	3.33	2.45	1.06	1.24	1.46	2.51	0.44	2.89
5.2	5.15	3.46	2.55	1.10	1.29	1.52	2.61	0.46	3.00
5.4	5.35	3.59	2.65	1.14	1.34	1.58	2.71	0.47	3.12
5.6	5.54	3.72	2.74	1.18	1.39	1.64	2.81	0.49	3.23
5.8	5.74	3.86	2.84	1.22	1.44	1.69	2.91	0.51	3.35
6.0	5.94	3.99	2.94	1.27	1.49	1.75	3.01	0.53	3.46
6.2	6.14	4.12	3.04	1.31	1.54	1.81	3.11	0.54	3.58
6.4	6.34	4.25	3.14	1.35	1.59	1.87	3.21	0.56	3.70
6.6	6.53	4.38	3.24	1.39	1.64	1.93	3.31	0.58	3.81
6.8	6.73	4.52	3.33	1.44	1.69	1.99	3.41	0.60	3.93
7.0	6.93	4.65	3.43	1.48	1.74	2.04	3.51	0.61	4.04
7.2	7.13	4.79	3.53	1.52	1.79	2.10	3.61	0.63	4.16
7.4	7.33	4.92	3.63	1.56	1.84	2.16	3.71	0.65	4.27
7.6	7.52	5.05	3.73	1.61	1.89	2.22	3.82	0.67	4.39
7.8	7.72	5.18	3.82	1.65	1.93	2.28	3.92	0.68	4.50
8.0	7.92	5.32	3.92	1.69	1.98	2.34	4.02	0.70	4,62
8.2	8.12	5.45	4.02	1.73	2.03	2.39	4.12	0.72	4.73
8.4	8.32	5.59	4.12	1.77	2.08	2.45	4.22	0.74	4.85
8.6	8.51	5.72	4.22	1.82	2.13	2.51	4.32	0.76	4.97
8.8	8.71	5.85	4.31	1.86	2.18	2.57	4.42	0.77	5.08
9.0	8.91	5.99	4.41	1.90	2.23	2.63	4.52	0.79	5.20
9.2	9.11	6.12	4.51	1.94	2.28	2.69	4.62	0.81	5.31
9.4	9.31	6.25	4.61	1.98	2.33	2.74	4.72	0.83	5.43
9.6	9.50	6.38	4.71	2.03	2.38	2.80	4.82	0.85	5.54
9.8	9.70	6.52	4.80	2.07	2.43	2.86	4.92	0.86	5.66
10.0	9.90	6.65	4.90	2.11	2.48	2.92	5.02	0.88	5.77

TABLE II. Pallet with Equidistant Lockings. Ratchet Wheel.

1	2	3	4	5	6		7		8		9	10	11
Diameter of wheel.		Circles of pallet.			Circles of lifting for the *total* angle of movement.						Height of segment.	Breadth of pallet arm.	Distance of centres.
Real 1.0	Measured 0.99	Locking 0.5774	Outer 0.7519	Inner 0.4029	8° 0.1543	0.2755	10° 0.1823	0.3210	12° 0.2167	0.3730	0.5425	0.6875	0.5774
5.0	4.95	2.89	3.76	2.01	0.77	1.38	0.91	1.60	1.08	1.87	2.71	0.44	2.89
5.2	5.15	3.00	3.91	2.10	0.80	1.43	0.95	1.67	1.13	1.94	2.82	0.46	3.00
5.4	5.35	3.12	4.06	2.18	0.83	1.49	0.98	1.73	1.17	2.01	2.93	0.47	3.12
5.6	5.54	3.23	4.21	2.26	0.86	1.54	1.02	1.80	1.21	2.09	3.04	0.49	3.23
5.8	5.74	3.35	4.36	2.34	0.89	1.60	1.06	1.86	1.26	2.16	3.15	0.51	3.35
6.0	5.94	3.46	4.51	2.42	0.93	1.65	1.09	1.93	1.30	2.24	3.26	0.53	3.46
6.2	6.14	3.58	4.66	2.50	0.96	1.71	1.13	1.99	1.34	2.31	3.36	0.54	3.58
6.4	6.34	3.70	4.81	2.58	0.99	1.76	1.17	2.05	1.39	2.39	3.47	0.56	3.70
6.6	6.53	3.81	4.96	2.66	1.02	1.82	1.20	2.12	1.43	2.46	3.58	0.58	3.81
6.8	6.73	3.93	5.11	2.74	1.05	1.87	1.24	2.18	1.47	2.54	3.69	0.60	3.93
7.0	6.93	4.04	5.26	2.82	1.08	1.93	1.28	2.25	1.52	2.61	3.80	0.61	4.04
7.2	7.13	4.16	5.41	2.90	1.11	1.98	1.31	2.31	1.56	2.69	3.91	0.63	4.16
7.4	7.33	4.27	5.56	2.98	1.14	2.04	1.35	2.38	1.60	2.76	4.01	0.65	4.27
7.6	7.52	4.39	5.71	3.06	1.17	2.09	1.39	2.44	1.65	2.84	4.12	0.67	4.39
7.8	7.72	4.50	5.86	3.14	1.20	2.15	1.42	2.51	1.69	2.91	4.23	0.68	4.50
8.0	7.92	4.62	6.02	3.22	1.23	2.20	1.46	2.57	1.73	2.98	4.34	0.70	4.62
8.2	8.12	4.73	6.17	3.30	1.27	2.26	1.49	2.63	1.78	3.06	4.45	0.72	4.73
8.4	8.32	4.85	6.32	3.38	1.30	2.31	1.53	2.70	1.82	3.13	4.56	0.74	4.85
8.6	8.51	4.97	6.47	3.46	1.33	2.37	1.57	2.76	1.86	3.21	4.67	0.76	4.97
8.8	8.71	5.08	6.62	3.54	1.36	2.42	1.60	2.83	1.91	3.28	4.77	0.77	5.08
9.0	8.91	5.20	6.77	3.63	1.39	2.48	1.64	2.89	1.95	3.36	4.88	0.79	5.20
9.2	9.11	5.31	6.92	3.71	1.42	2.53	1.68	2.95	1.99	3.43	4.99	0.81	5.31
9.4	9.31	5.43	7.07	3.79	1.45	2.59	1.71	3.02	2.04	3.51	5.10	0.83	5.43
9.6	9.50	5.54	7.22	3.87	1.48	2.64	1.75	3.08	2.08	3.58	5.21	0.85	5.54
9.8	9.70	5.56	7.37	3.95	1.51	2.70	1.79	3.15	2.12	3.66	5.32	0.86	5.66
10.0	9.90	5.77	7.52	4.03	1.54	2.75	1.82	3.21	2.17	3.73	5.43	0.88	5.77

The columns containing the circles of pallets require no explanation, after what has been said in Chapter V.

The columns 5, 6 and 7 in Table I and 6, 7 and 8 in Table II indicate the lifting circles. These circles will require some explanation.

The exact angle of inclination for the driving planes to give the intended lifting effect can be very conveniently measured by the diameters of circles to which the prolongations of the driving planes are tangents, and in the next chapter it will be shown how to use these circles. In the tables they are for the sake of brevity called lifting circles, and their diameters are calculated for the three angles of movement: 8°, 10° and 12°, as already mentioned. In Table II there are two diameters given in every column, because for a pallet with equidistant lockings the lifting circles for each pallet arm are not equal, as is the case with those of the circular pallet.

The column 8 in Table I and 9 in Table II indicate the height of a segment, serving to determine the outer corners of the pallet. The diameter for the circle of this segment is that of the largest circle of pallet, and it must be imagined to be flattened away by a straight line, to show the height indicated in the table.

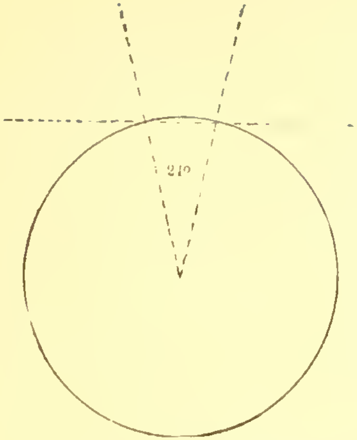
The two last columns contain the breadth of pallet arms, which is the same for both the tables, and the distance of pitch for which the parts are intended, and which cannot be altered without making the escapement defective. •

The following explanations may serve for the use of those who take an interest in the method of establishing these tables, but it may be repeated here that for the use of the tables themselves it is by no means necessary to go through these calculations, because the tables are the results of them, and may be used by a person who knows nothing at all of mathematics. Another reason for giving these detailed explanations is to facilitate, to those who have had a good education, the solution of problems which are out of the common way. Besides, he who writes a book must be aware that it is dedicated to future times and to coming generations, and from all that has been said by the most competent English horologists there prevails the conviction that superiority in our time cannot be secured by mere practical skill, but on the contrary the task of our days must be to give to every workman a good and thorough education, in order to enable him to apply the aid of science directly to his practical pursuits.

The calculations were originally made with five and six decimals, and the result shortened down to the more convenient length of four decimals. This will account for small differences that may be observed in the last decimals. All the angles in the following calculations have been rounded off, so that differences of less than 5′ have been dropped, as they are too minute to perceptibly influence the working sizes. The woodcut diagrams accompanying these calculations are merely meant to facilitate the understanding of the lines and angles spoken of. They serve for very different angles and proportions, and it must be remarked here that they are not intended to give the proportions and angularities of each special case, but only to give a general impression of the part of the escapement just in question.

TABLE I.—COLUMNS ONE AND TWO.

The column 2 contains the measured diameter of the escape wheel. This measured diameter is = the real diameter less the height of arc of the central angle of 24°, contained between two points of teeth. (See the diagram.)



For a diameter of the circle = 1, the height of arc of the angle of 24° is = 0.0109, of which number the last two decimals may be omitted.

Consequently, the measured diameter of a wheel is = the real diameter less 0.01, or in this case = 1 — 0.01 = 0.99. This is the proportional number at the head of column 2.

For wheels of any greater or smaller number of teeth, the difference between measured and real diameter is different, because the angle of 24° belongs only to the wheel of 15 teeth.

COLUMN THREE.

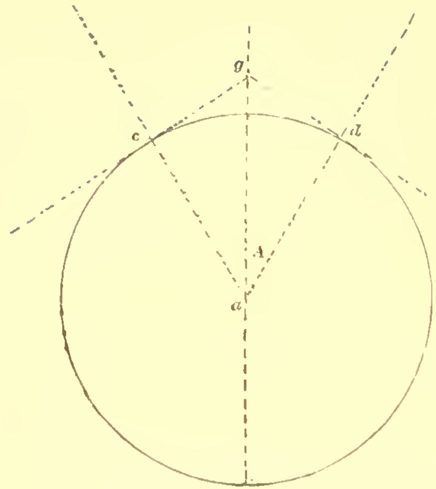
The diameter of the outer circle of the (circular) pallet is the sum of the diameter of the locking circle + the breadth of pallet arm. This latter, equal to an arc of 10° of the wheel's circumference, would be for the diameter of wheel = 1:

$$\frac{1 \,.\, 3.1416 \,.\, 10}{360} = \frac{3.1416}{36} = 0.08727.$$

The diameter of the locking circle is found in the following way: Given the diameter of wheel = 1.

The radius $a\,d$ = 0.5

$< A = 30°$.



$d\,g = a\,d.$ tang $A.$ = 0.5. tang 30°. = 0.5. 0.5774.*) = 0.2887.

$d\,g$ is the radius of the locking circle, and consequently the diameter of this circle must be:

2 . 0.2882 = 0.5774.

The diameter of outer circle, as it has been previously explained, is = :

0.5774 + 0.0873 = 0.6647.

COLUMN FOUR.

The diameter of the inner pallet circle is, by the construction of the escapement (Diagram 2) equal to the diameter of locking circle less the breadth of pallet arm:

0.5774 — 0.0873 = 0.4901.

COLUMNS FIVE, SIX AND SEVEN.

The calculation of the lifting circles corresponding to the lifting angles 7°, 8½° and 10½° is the following.

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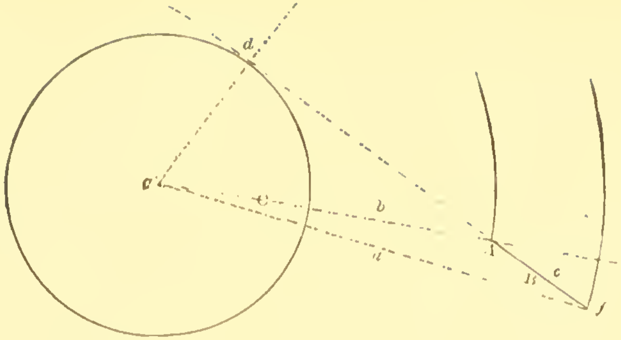
*The value of this tangent and of all trigonometric functions will be found in any good handbook of mathematics or navigation.



Of the triangle $a\ b\ c$ the known parts are:

$$a = \frac{0.6647}{2} = 0.3323 \text{ (radius of outer circle)}$$

$$b = \frac{0.4901}{2} = 0.245 \text{ (radius of inner circle)}$$

$$C = 7°, \text{ or } 8\tfrac{1}{2}° \text{ or } 10\tfrac{1}{2}°.$$

$$5)\quad C = 7°$$

$$*\ \frac{A + B}{2} = 90° - \frac{C}{2} = 90° - 3°\ 30' = 86°\ 30'$$

$$\text{tang.}\left(\frac{A - B}{2}\right) = \frac{a - b}{a + b} \text{ cotang. } \frac{C}{2}$$

$$= \frac{0.3323 - 0.245}{0.3323 + 0.245} \text{ cotang. } 3°\ 30'$$

$$= \frac{0.0873}{0.5773} \text{ cotang. } 3°\ 30'$$

log. 873 = 2.9410

+ log. cotang. 3° 30′ = 11.2135

14,1545

— log. 5773 = 3.7614

*In all these calculations the capital letters signify angles and the lower case letters, lines.

$$\text{log. tang.}\left(\frac{A - B}{2}\right) = 10.3931$$

$$< \frac{A - B}{2} = 68°$$

$$< \frac{A + B}{2} = 86°\ 30'$$

Hence follows:

$A = 86°\ 30' + 68° = 154°\ 30'$

$B = 86°\ 30' - 68° = 18°\ 30'$

C (already known) = 7° —′

180° —′

(The sum of the three angles in each triangle.)

This calculation was made for the purpose of finding the value of the angle B. This angle serves now to determine the line $g\ d$ in the rectangular triangle $g\ d\ f$, of which is known:

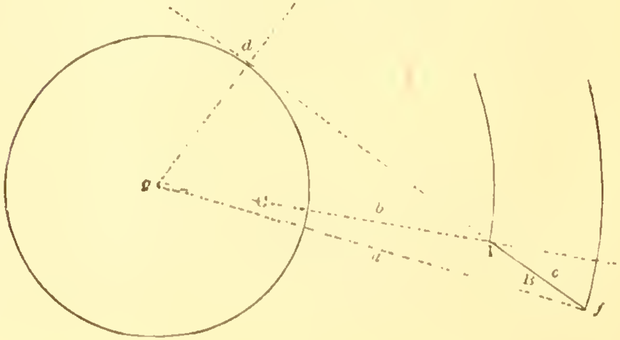
The hypothenuse $g\ f$	0.3323.
and $< B$	18° 30′

$g\ d = g\ f \sin. B = 0.3323 \sin. 18°\ 30'$

$= 0.3323 \cdot 0.3173 = 0.1054$

The line $g\ d$ is the radius of the lifting circle, and accordingly the diameter of it is

$$= 0.1054 \cdot 2 = 0.2108$$



$$6)\ \angle C = 8\tfrac{1}{2}^\circ$$

$$\frac{A+B}{2} = 90^\circ - \frac{C}{2} = 90 - 4^\circ\ 15' = 85^\circ\ 45'$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b}\ \text{cotang.}\ \frac{C}{2} = \frac{0.0873}{0.5773}\ \text{cotang.}\ 4^\circ\ 15'$$

$$\begin{aligned} \log.\ 873 &= 2.9410 \\ +\ \log.\ \text{cotang.}\ 4^\circ\ 15' &= 11.129 \\ &\ 14.0700 \\ -\ \log.\ 5773 &= 3.7614 \\ \log.\ \text{tang.}\left(\frac{A-B}{2}\right) &= 10.3086 \end{aligned}$$

$$\frac{A-B}{2} = 63^\circ\ 50'$$

$$\frac{A+B}{2} = 85^\circ\ 45'$$

$$B = 85^\circ\ 45' - 63^\circ\ 50' = 21^\circ\ 55'$$

$$g\,d = g\,f \sin B = 0.3323\ .\ \sin 21^\circ\ 55'$$
$$= 0.3323\ .\ 0.3733 = 0.124047.$$

Diameter of lifting circle $= 2\ .\ 0.124$
$= 0.248$

$$7)\ \angle C = 10\tfrac{1}{2}^\circ.$$

$$\frac{A+B}{2} = 90^\circ\ \frac{C}{2} = 90^\circ - 5^\circ\ 15' = 84^\circ\ 45'$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{0.0873}{0.5773}\ \text{cotang.}\ 5^\circ\ 15'$$

$$\begin{aligned} \log.\ 873 &= 2.9410 \\ +\ \log.\ \text{cotang.}\ 5^\circ\ 15' &= 11.0368 \\ &\ 13.9778 \\ -\ \log.\ 5773 &= 3.7614 \\ \log.\ \text{tang.}\left(\frac{A-B}{2}\right) &= 10.2164 \end{aligned}$$

$$\frac{A-B}{2} = 58^\circ\ 45'$$

$$B = 84^\circ\ 45' - 58^\circ\ 45' = 26^\circ$$

$$d\,g = g\,f \sin B = 0.3323\ .\ 0.\ 4384 = 0.146.$$

Diameter of lifting circle $= 2\ .\ 0.146$
$= 0.292$

Thus the diameters of the lifting circles for the three lifting angles are:

Diam. of	7°	$8\frac{1}{2}$°	$10\frac{1}{2}$°
wheel = 1.	0.211	0.248	0.292

COLUMN EIGHT.

The eighth column indicates the height of a segment of the outer circle of pallet (diameter = 0.6647), which serves to find the outer corners of the pallet.

This height is calculated in the following way:

Of the triangle $h\,g\,i$ the known parts are:

$g\,h = g\,i = 0.3323$ (radius of outer circle.)

Of the two rectangular triangles $a\,c\,g$ and $a\,d\,g$ the two angles in a are by construction 30° each, and consequently the two other angles in g must be 60° each.

The sum of the two angles in the angle $h\,g\,l = 120^\circ$.

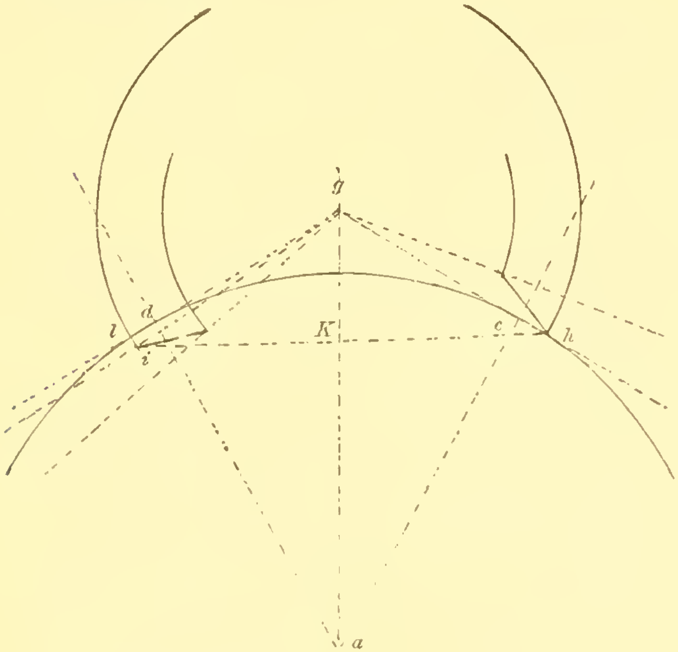
The angle $h\,g\,i$ is $= \angle h\,g\,l - \angle l\,g\,i = 120^\circ - 1^\circ\ 30'$ (locking angle) $= 118^\circ\ 30'$.

The sides $g\,h$ and $g\,i$ being equal, the angles opposite to them must be equal too:

$$\angle g\,h\,i = \angle g\,i\,h = \frac{180^\circ - 118^\circ\ 30'}{2}$$

$$= \frac{61^\circ\ 30'}{2} = 30^\circ\ 45'$$

A perpendicular line drawn from the point g to the line $h\,i$ divides the triangle $g\,h\,i$ in two equal rectangular triangles. This perpendicular line does not coincide completely with the line of centres $g\,a$, but as the divergence of these two lines is but $\frac{3}{4}$°, it may be neglected altogether in the drawing. We suppose then the point k to be the point of intersection, and the two rectangular triangles are: $g\,h\,k$ and $g\,i\,k$.



In these two triangles we know:

$g\,h = g\,i = 0.3323.$

$< g\,h\,i = < g\,i\,h = 30°\ 45'$

$g\,k = g\,i\ .\ \sin\ .\ g\,i\,h = 0.3323\ .\ \sin\ .\ 30°\ 45'$

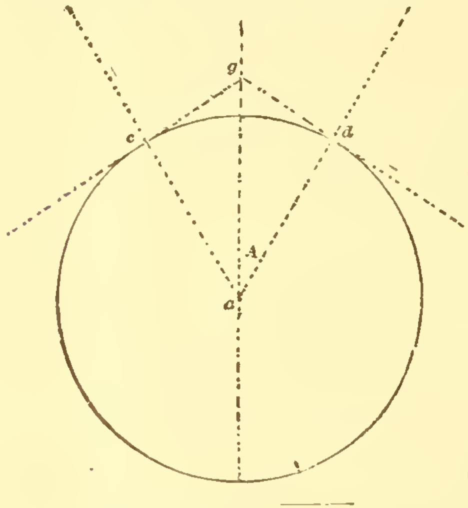
$= 0.3323\ .\ 0.5112 = 0.1699$

The sum of the radius of the outer circle = 0.3323
and the line $g\,k$ = 0.1699
0.5022

is the height of segment required.

COLUMN NINE.

The breadth of pallet arm has already been indicated as being equal to the opening of an angle of 10° at the wheel's centre, measured at the circumference of the wheel. This breadth is = 0.0873 for the diameter of the wheel = 1.



COLUMN TEN.

The distance of centres can be found by the rectangular triangle $a\,c\,g$, of which we know: $a\,c = 0.5 <$ $c\,a\,g = 30°$ (by construction.)

$$a\,g = \frac{a\,c}{\cos.\ c\,a\,g} = \frac{0.5}{\cos.\ 30°} = \frac{0.5}{0.866} = 0.5774.$$

TABLE II. COLUMNS ONE AND TWO.

The real and measured diameters of wheel are unaltered.

COLUMN THREE.

The circle of locking is the same as it has been found when calculating Table 1; its diameter is = 0.5774.

COLUMN FOUR.

The diameter of the outer circle is the sum of
the diameter of locking circle = 0.5774.
+ double the breadth of pallet arm = 0.1745.
0.7519.

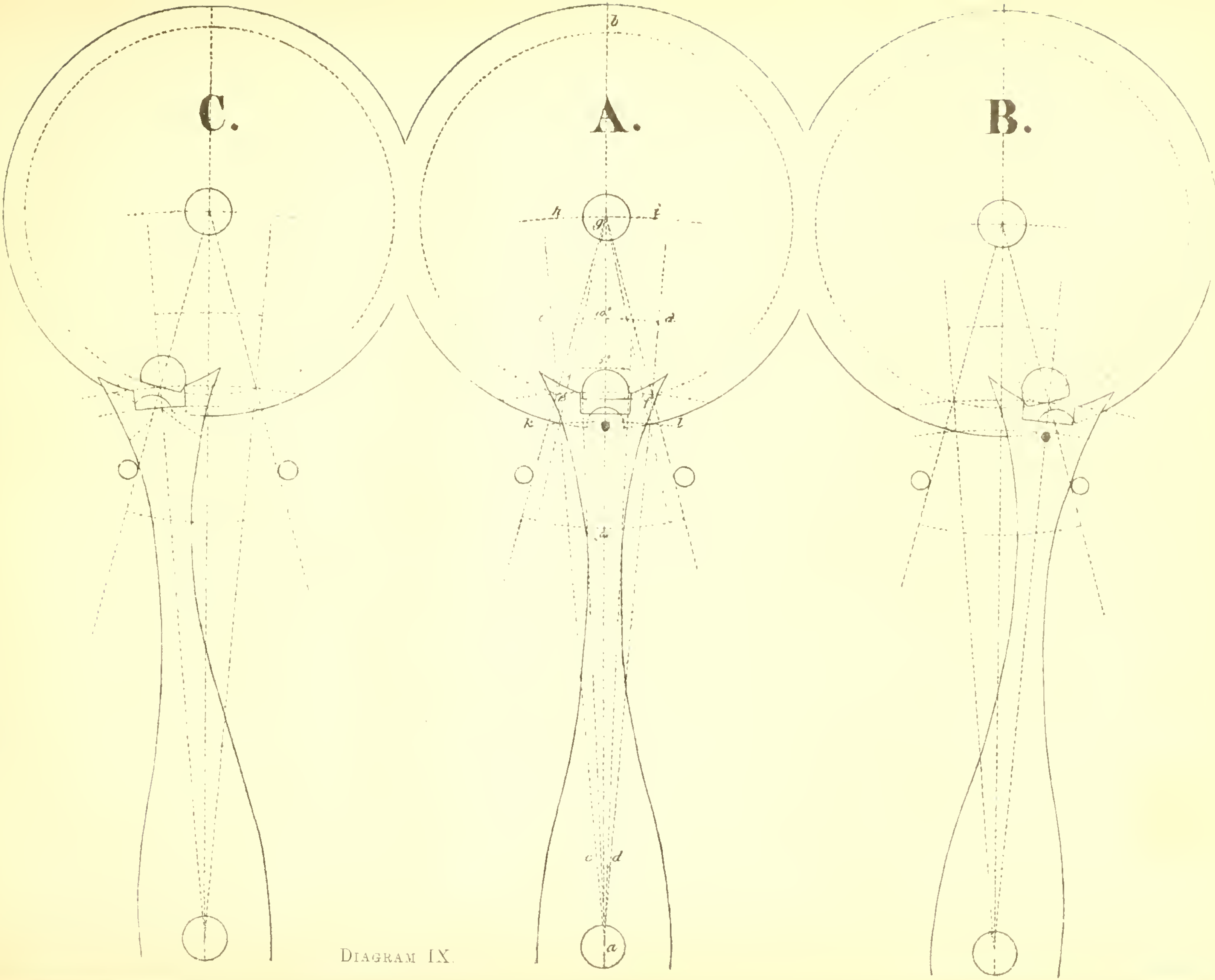


Diagram IX.

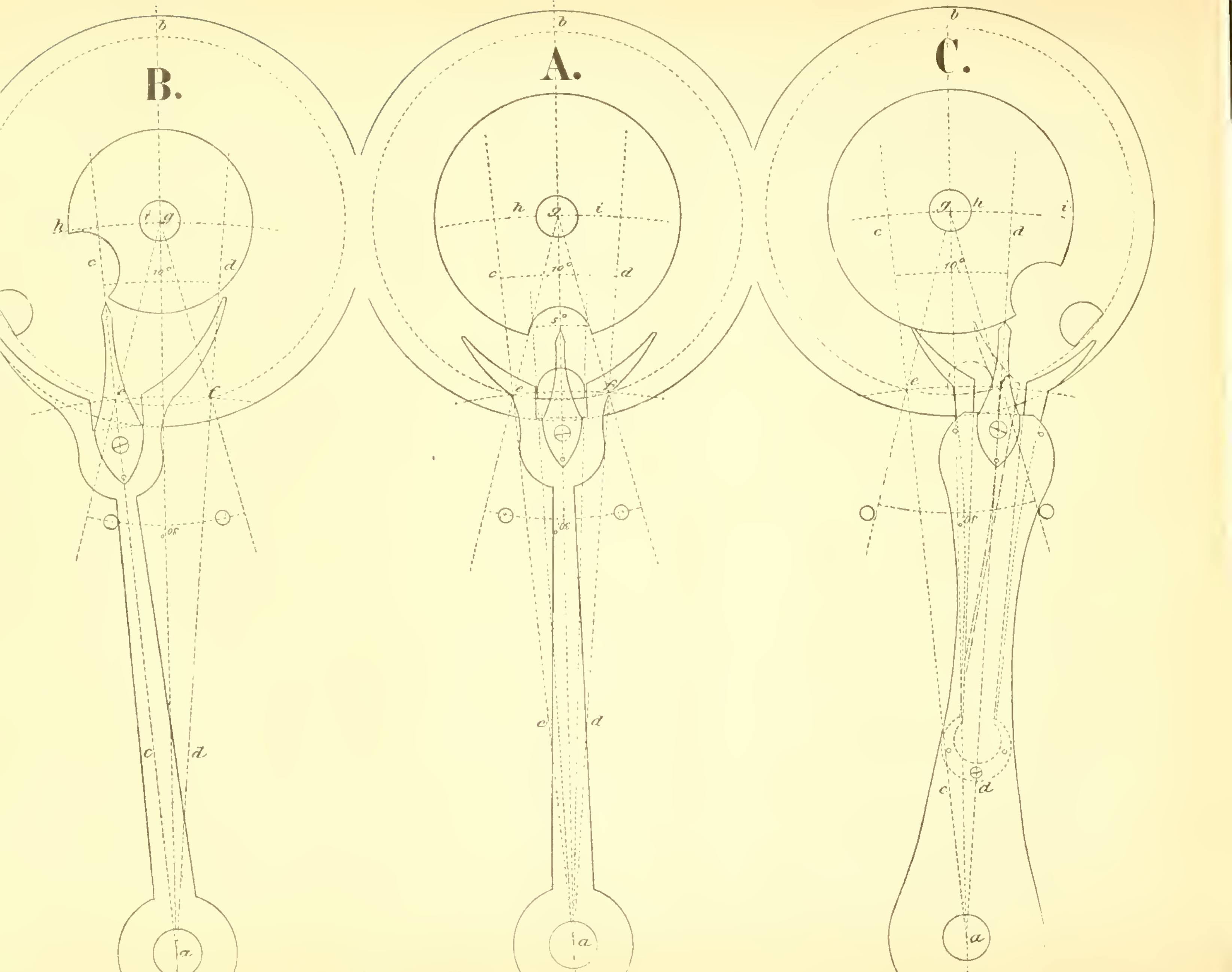


Diagram X.

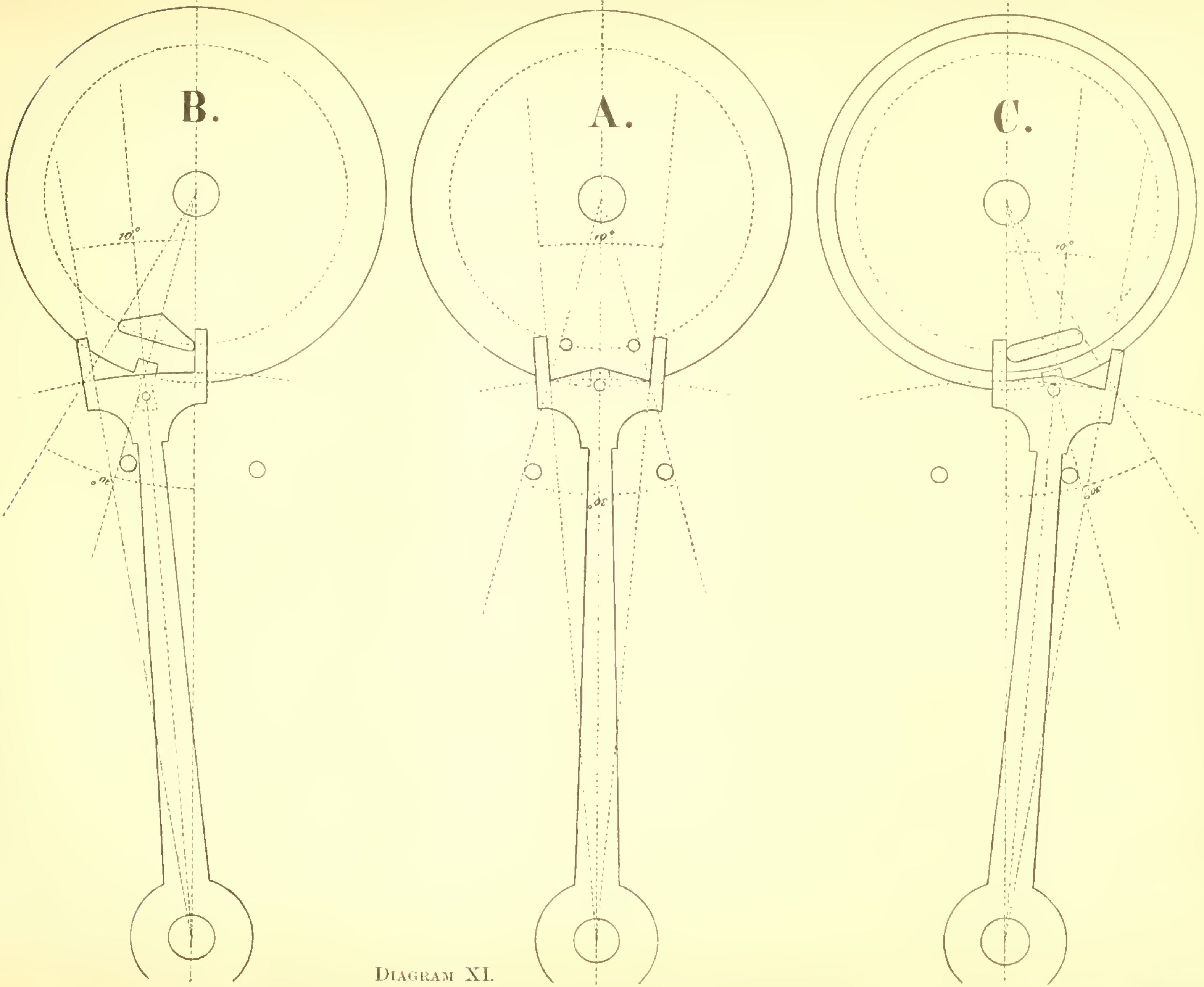


Diagram XI.

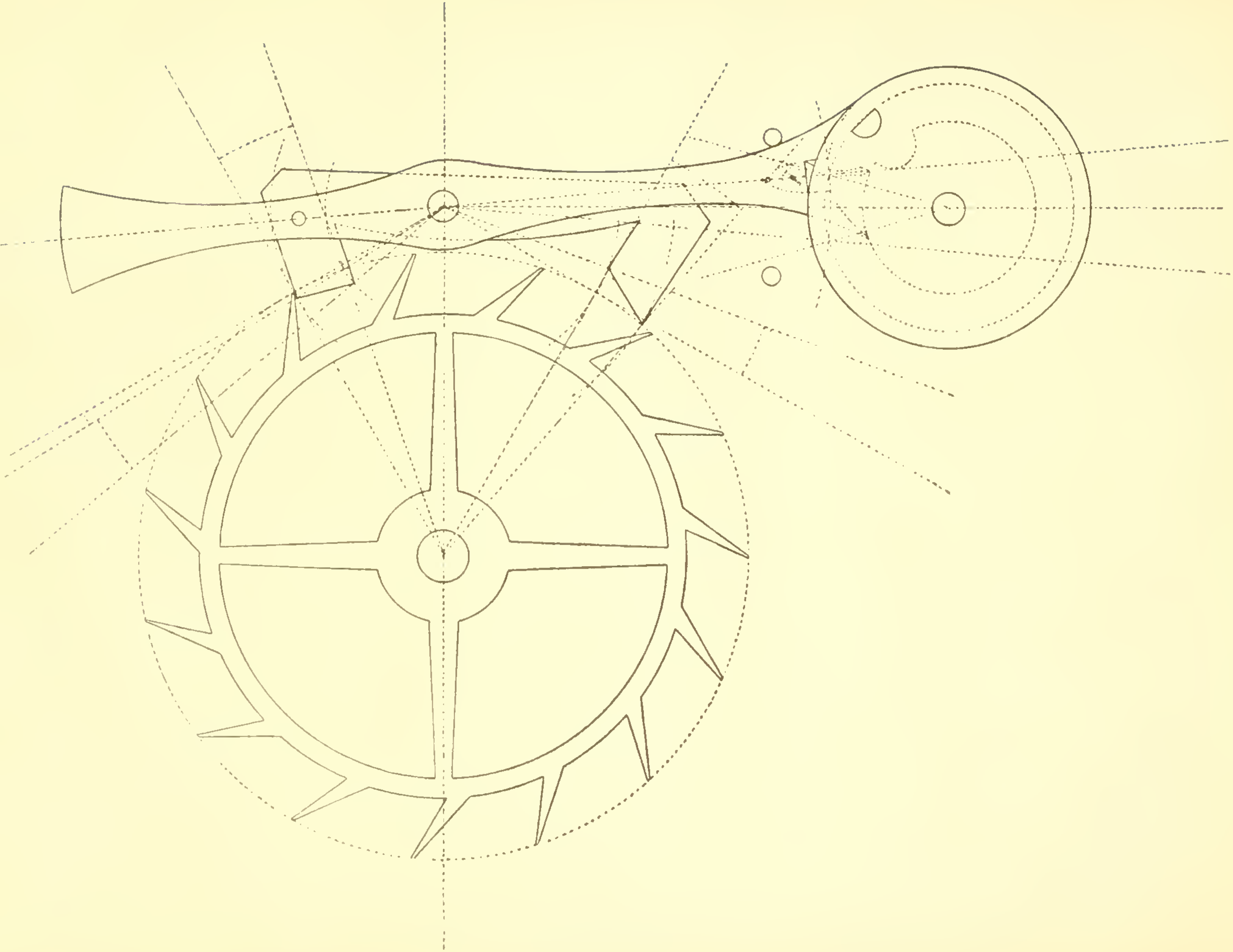


Diagram XII.

COLUMN FIVE.

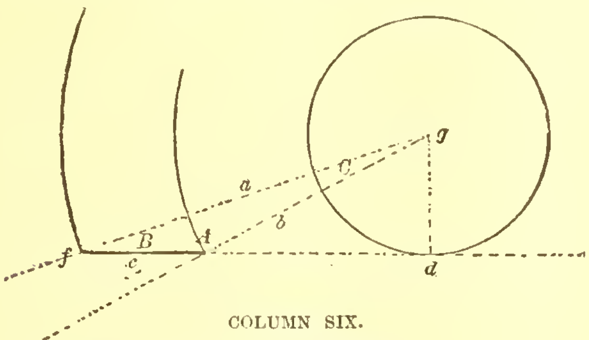
The diameter of the inner pallet circle is the difference of

the diameter of locking circle	$= 0.5774.$
— double the breadth of pallet arm	$= 0.1745.$
	$0.4029.$

COLUMNS SIX, SEVEN AND EIGHT.

The diameters of lifting circles are, for a pallet with equi-distant lockings, different for the driving plane of each pallet arm, therefore the column for each lifting angle contains two numbers, the lower of which is the diameter of lifting circle for the first driving plane, and the higher number that for the driving plane of the second pallet arm.

The way of calculating these numbers is the same as before described, only substituting the different radii.



COLUMN SIX.

$C = 7°$. First arm.

Of the triangle $a\,b\,c$ we know:

$a = 0.2887.$ (radius of locking circle)

$b = 0.2015.$ (radius of inner circle)

$C = 7°.$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 3°\,30' = 86°\,30'$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b}\ \text{cotang.}\ \frac{C}{2}$$

$$= \frac{0.2887-0.2015}{0.2887+0.2015}.\ \text{cotang.}\ 3°\,30'$$

$$= \frac{0.0873}{0.4902}.\ \text{cotang.}\ 3°\,30'$$

	log. 873 $=$	2.9410
+ log. cotang. 3° 30′	$=$	11.2135.
		14.1545.
— log. 4902	$=$	3.69037.
log. tang. $\left(\frac{A-B}{2}\right)$	$=$	10.46413.

$$\frac{A-B}{2} = 71°$$

$B = 86°\,30' - 71° = 15°\,30'$

$g\,d = g\,f \sin B \quad = 0.2887 .\, . 0.2672$

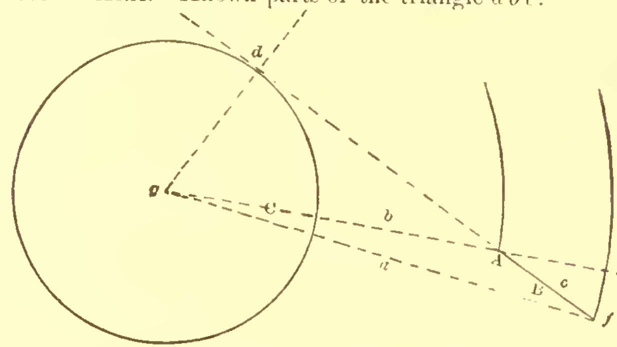
$= 0.07713$

Diameter of lifting circle for the first pallet arm

$2\,.\,g\,d = 2\,.\,0.07713$

$= 0.543.$

SECOND ARM.—Known parts of the triangle $a\,b\,c$:



$a = 0.3759$ (radius of outer circle)

$b = 0.2887$ (radius of locking circle)

$C = 7°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 3° \, 30' = 86° \, 30'$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{0.3759-0.2887}{0.3759+0.2887} \cdot \text{cotang.} \frac{C}{2}$$

$$= \frac{0.0873}{0.6646} \cdot \text{cotang. } 3° \, 30'$$

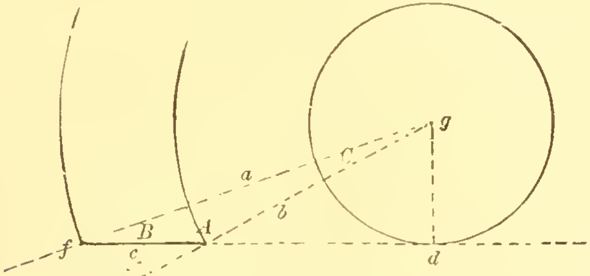
$$\begin{aligned} \text{log. } 873 &= 2.9410. \\ + \text{ log. cotang. } 3° \, 30' &= 11.2135 \\ & 14.1545 \\ - \text{ log. } 6646 &= 3.82256 \\ \text{log. tang.}\left(\frac{A-B}{2}\right) &= 10.33194 \end{aligned}$$

$$\frac{A-B}{2} = 65° \qquad B = 86° \, 30' - 65° = 21° \, 30'$$

$$gd = gf \text{ sin. } B = 0.3759 \, . \, 0.3665.$$
$$= 0.1378.$$

Diameter of the lifting circle of the second pallet arm

$$= 2 \, . \, gd = 2 \, . \, 0.1378$$
$$= 0.2755.$$



COLUMN SEVEN.

$< C = 8\frac{1}{2}°$. First arm.

$a = 0.2887$

$b = 0.2015$ $\qquad C = 8\frac{1}{2}°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 4° \, 15' = 85° \, 45'$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b} \text{ cotang. } \frac{C}{2} = \frac{0.0873}{0.4902} \cdot \text{cotang. } 4° \, 15'$$

$$\begin{aligned} \text{log. } 873 &= 2.9410 \\ + \text{ log. cotang. } 4° \, 15' &= 11.12894 \\ & 14.06994 \\ - \text{ log. } 4902 &= 3.69037. \\ \text{log. tang.}\left(\frac{A-B}{2}\right) &= 10.37957 \end{aligned}$$

$$\frac{A-B}{2} = 67° \, 20'$$

$$B = 85° \, 45' - 67° \, 20' = 18° \, 25'$$

$$gd = gf \text{ sin. } B = 0.2887 \, . \, 0.3158 = 0.09117$$

Diameter of lifting circle of the first pallet arm

$$= 2 \, . \, gd = 2 \, . \, 0.09117 = 0.1823.$$

SECOND ARM.

$a = 0.3759$ $\qquad C = 8\frac{1}{2}°$

$b = 0.2887$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 4° \, 15' = 85° \, 45'$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b} \cdot \text{cotang. } \frac{C}{2}$$

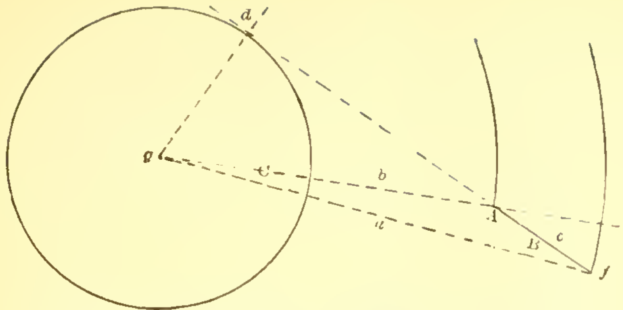
$$= \frac{0.0873}{0.6647} \cdot \text{cotang. } 4° \, 15'$$

$$\begin{aligned} \text{log. } 873 &= 2.9410 \\ + \text{ log. cotang. } 4° \, 15' &= 11.12894 \\ & 14.06994 \\ - \text{ log. } 6647 &= 3.82256 \\ \text{log. tang.}\left(\frac{A-B}{2}\right) &= 10.24738 \end{aligned}$$

$$\frac{A-B}{2} = 60° \, 30'$$

$$B = 85° \, 45' - 60° \, 30' = 25° \, 15'$$

$$gd = gf \text{ sin. } B = 0.3759 \, . \, \text{sin. } 25° \, 15'$$
$$= 0.3759 \, . \, 0.4267$$
$$= 0.16035$$



Diameter of lifting circle of the second pallet arm

$= 2 \,.\, g\,d = 2 \,.\, 0.16035$

$= 0.3207$

COLUMN EIGHT.

$C = 10\frac{1}{2}°$. First arm.

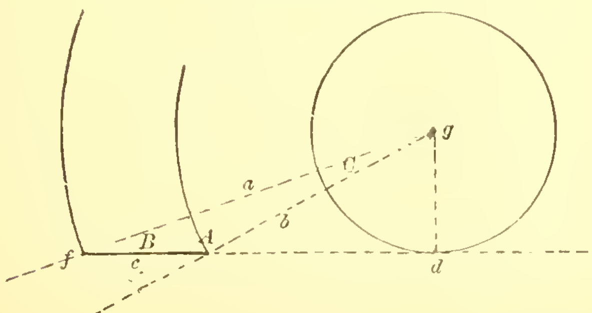
$a = 0.2887.$ $\qquad C = 10° \, 30'$

$b = 0.2015.$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 5° \, 15' = 84° \, 45'$$

$$\text{tang.} \left(\frac{A-B}{2}\right) = \frac{a-b}{a+b} \text{ cotang. } \frac{C}{2}$$

$$= \frac{0.0873}{0.4902} \text{ cotang. } 5° \, 15'$$



$$\text{log. } 873 = 2.9410.$$

$$+ \text{ log. cotang. } 5° \, 15' = 11.03674$$

$$13.97774$$

$$- \text{ log. } 4902 = 3.69037$$

$$\text{log. tang.} \left(\frac{A-B}{2}\right) = 10.28737$$

$$\frac{A-B}{2} = 62° \, 40'$$

$$B = 84° \, 45' - 62° \, 40' = 22° \, 5'$$

$$g\,d = g\,f \text{ sin. . } B = 0.2887 \,.\, 0.3758.$$

$$= 0.10837$$

Diameter of lifting circle of the first pallet arm

$= 2 \,.\, g\,d = 2 \,.\, 0.10837$

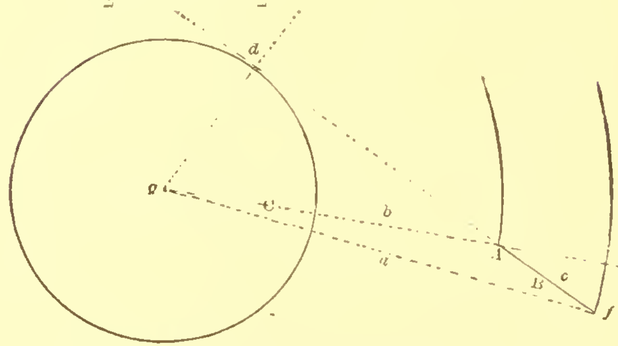
$= 0.267,$

SECOND ARM.

$a = 0.3759$ $\qquad C = 10\frac{1}{2}°$

$b = 0.2887$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 5° \, 15' = 84° \, 45'$$



$$\text{tang.} \left(\frac{A-B}{2}\right) = \frac{a-b}{a+b} \text{ cotang. } \frac{C}{2}$$

$$= \frac{0.0873}{0.6646} \text{ cotang. } 5° \, 15'$$

$$\text{log. } 873 = 2.9410$$

$$+\ \text{log. cotang. } 5^\circ\ 15' \quad 11.0368$$

$$13.9778$$

$$-\ \text{log. } 6647 \quad 3.82256$$

$$\text{log. tang.} \left(\frac{A-B}{2}\right) = 10.15524$$

$$\frac{A-B}{2} = 55^\circ$$

$$B = 84^\circ\ 45' - 55^\circ = 29^\circ\ 45'$$

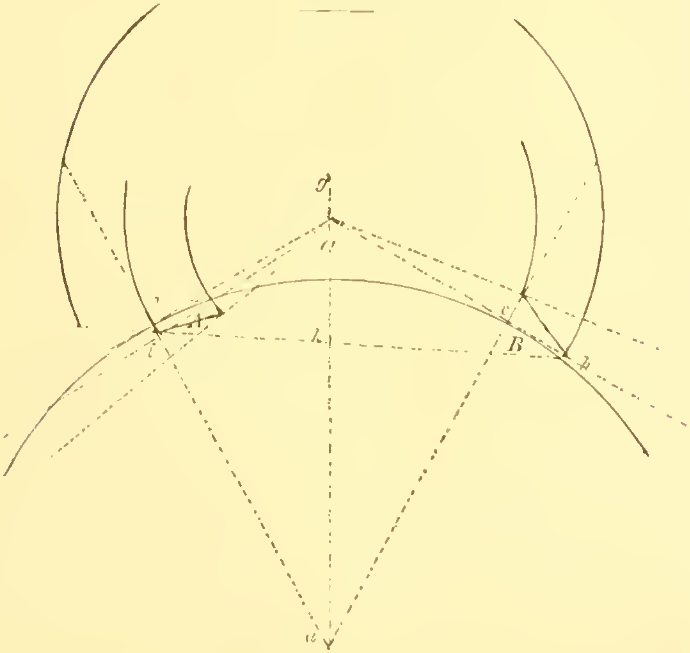
$$g\,d = g\,f \text{ sin. } B = 0.3759 \,.\, 0.4963$$

$$= 0.18656.$$

Diameter of lifting circle of the second pallet arm

$$= 2 \,.\, g\,d = 2.\ 0.18656$$

$$= 0.373$$



COLUMN NINE.

The height of segment in this case is not quite as easily to be found as that for the circular pallet, because of the triangle $g\,h\,i$ the two sides $g\,h$ and $g\,i$, and consequently the angles opposite to them, are not equal; so that the known parts are only:

$g\,i$ (radius of locking circle) $= 0.2887$.
$g\,h$ (radius of outer circle) $= 0.3759$.
$< i\,g\,h = 118^\circ\ 30'$

To shorten the formulæ, we substitute for

$g\,h$ — a
$g\,i$ — b
$h\,i$ — c

and call the angles opposite to these sides A, B and C.

$$\frac{A+B}{2} = 90^\circ - \frac{C}{2} = 90^\circ - \frac{118^\circ\ 30'}{2}$$

$$= 90^\circ - 59^\circ\ 15$$

$$= 30^\circ\ 45'$$

$$\text{tang.} \left(\frac{A-B}{2}\right) = \frac{a-b}{a+b} \text{ cotang. } \frac{C}{2}$$

$$= \frac{0.376-0.2887}{0.376+0.2887} \text{ cotang. } 59^\circ\ 15'$$

$$= \frac{0.0873}{0.6647} \text{ cotang. } 59^\circ\ 15'$$

$$\text{log. } 873 = 2.9410$$

$$+\ \text{log. cotang. } 59^\circ\ 15' = 9.77447.$$

$$12.71547$$

$$-\ \text{log. } 6647 = 3.82262$$

$$\text{log. tang.} \left(\frac{A-B}{2}\right) = 8.89285$$

$$\frac{A-B}{2} = 4^\circ\ 28' \text{ and } \frac{A+B}{2} = 30^\circ\ 45'$$

$$B = \frac{A+B}{2} - \frac{A-B}{2} = 30^\circ\ 45' - 4^\circ\ 28'$$

$$= 26^\circ\ 17'$$

The angle B being found, we have in the rectangular triangle $g\ h\ k$

$$\text{the hypothenuse } g\,h = 0.376$$
$$< g\,h\,k = B \qquad = 26° \ 17'$$
$$g\,k = g\,h \text{ sin. } B. = 0.376 \ . \text{ sin. } 26° \ 17$$
$$= 0{,}376. \ 0{,}4428$$
$$= 0.1665.$$

The sum of the radius of outer pallet circle	$= 0.376$
+ the line $g\,k$	$= 0.1665$
is the required height of segment	$= 0.5425$

Explanations of the Columns in Tables III and IV.

Column One.—The primitive circle of wheel is the circle laid through the fore edges of the teeth. This circle is called the primitive circle because it serves as base for the construction, the locking being performed in it.

In all the calculations the diameter of primitive circle is supposed = 1.

Column Two.—This column indicates the diameter of the theoretical circle embracing the outer edges of the teeth.

Column three contains the measured size of the outer circle, as explained when treating the ratchet wheel.

The columns four and five in Table III, and four, five and six in Table IV give the circles of pallet corresponding to those of the ratchet wheel pallet.

The columns for the lifting circles, height of segment, breadth of pallet arm and distance of centres are quite analogous to those in the ratchet wheel tables.

There is still the column indicating the breadth of wheel teeth before making the inclined plane. This serves for making the cutter for the wheel of the right breadth.

Finally, the tangent circles serve to draw the inclined planes on the wheel teeth with the proper angularity.

Table III. Calculations.

Columns Two and Three.—The outer diameter is to be calculated in this way:

The lifting angle to be performed by the wheel teeth is supposed to be 2° for a pallet of 8° of total movement, and 8½° for those of 10° and 12° of total movement.

For these latter the projection of the inclined end of the tooth beyond the primitive diameter is:

$a = b$ tang. A.

$b =$ (rad. of locking circle)

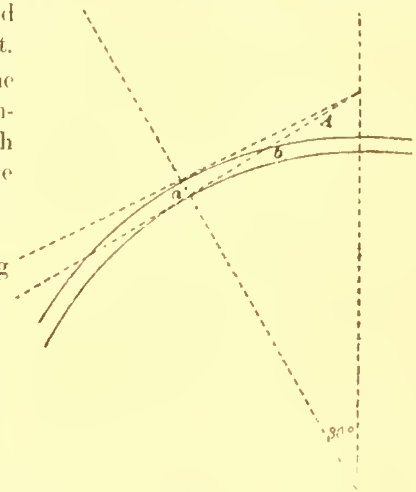
$= 0.2887.$

$A = 2\frac{1}{2}°$

$a = 0.2887$. tang. A

$= 0.2887$. 0.0437

$= 0.0126$



$$\text{Outer diameter} = 1 + 2 \ . \ 0.0126$$
$$= 1 + 0.252 = 1.0252$$
$$\text{Measured diameter} = 1.0252 \ . \ 0.99 = 1.0149$$

For the pallet of 8°, $A = 2°$, and consequently:

$$a = b \text{ tang. } A = 0.2887 \ . \text{ tang. } 2°$$
$$= 0.2887 \ . \ 0.0349.$$
$$= 0.010075$$
$$\text{Outer diameter} = 1 + 2 \ . \ 0.010075$$
$$= 1 + 0.02015$$
$$= 1.02015$$

This number presents so very small a difference to that referring to the angle of 2½°, that we refrain from forming a separate column for it, which would only complicate the

TABLE III. Circular Pallet—Club Wheel.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Diameter of wheel circle			Circles of pallet		Lifting circles for the total angle of movement:			Height of segment	Breadth of pallet arm	Breadth of wheelteeth before inclining	Tangent circles for the inclined planes of teeth		Distance of centres
Primitive	Outer Real	Outer Measured	Outer	Inner	8°	10°	12°				8°	10° and 12°	
1.00.	1.0126	1.0025	0.6385	0.5163	0.2183	0.2537	0.3144	0.4825	0.06108	0 0305	0.9688	0.9476	0.5774
5.0	5.06	5.01	3.19	2.58	1.09	1.27	1.57	2.41	0.31	0.15	4.84	4.74	2.89
5.2	5.27	5.21	3.32	2.69	1.14	1.32	1.63	2.51	0.32	0.16	5.04	4.93	3.00
5.4	5.47	5.41	3.45	2.79	1.18	1.37	1.70	2.61	0.33	0.16	5.23	5.12	3.12
5.6	5.67	5.61	3.58	2.89	1.22	1.42	1.76	2.70	0.34	0.17	5.43	5.31	3.23
5.8	5.87	5.81	3.70	3.00	1.27	1.47	1.82	2.80	0.35	0.18	5,62	5.50	3,35
6.0	6.08	6.02	3.83	3.10	1.31	1.52	1.89	2.90	0.37	0.18	5.81	5.69	3.46
6.2	6.28	6.22	3.96	3.20	1.35	1.57	1.95	2.99	0.38	0.19	6.01	5.88	3.58
6.4	6.48	6.42	4.09	3.30	1.40	1.62	2.01	3.09	0.39	0.20	6.20	6.06	3.70
6.6	6.68	6.62	4.21	3.41	1.44	1.67	2.08	3.18	0.40	0.20	6.39	6.25	3.81
6.8	6.89	6.82	4.34	3.51	1.48	1.73	2.14	3.28	0.42	0.21	6.59	6.44	3.93
7.0	7.09	7.02	4.47	3.61	1.53	1.78	2.20	3.38	0.43	0.21	6.78	6.63	4.04
7.2	7.29	7.22	4.60	3.72	1.57	1.83	2.26	3.47	0.44	0.22	6.98	6.82	4.16
7.4	7.49	7.42	4.72	3.82	1.62	1.88	2.33	3.57	0.45	0.23	7.17	7.01	4.27
7.6	7.70	7.62	4.85	3.92	1.66	1.93	2.39	3.67	0.46	0.23	7.36	7.20	4,39
7.8	7.90	7.82	4.98	4.03	1.70	1.98	2.45	3.76	0.48	0.24	7.56	7.39	4.50
8.0	8.10	8.02	5.11	4.13	1.75	2.03	2.52	3.86	0.49	0.24	7.75	7.58	4.62
8.2	8.30	8.22	5.24	4.23	1.79	2.08	2.58	3.96	0.50	0.25	7.94	7.77	4.73
8.4	8.51	8.42	5.36	4.34	1.83	2.13	2.64	4.05	0.51	0.26	8.14	7.96	4.85
8.6	8.71	8.62	5.49	4.44	1.88	2.18	2.70	4.15	0.53	0.26	8.33	8.15	4.97
8.8	8.91	8.82	5.62	4.54	1,92	2.23	2.77	4.25	0.54	0.27	8.53	8.34	5.08
9.0	9.11	9.02	5.75	4.65	1.96	2.28	2.83	4.34	0.55	0.27	8.72	8.53	5.20
9.2	9.32	9.22	5.87	4.75	2.01	2.33	2.89	4.44	0.56	0.28	8.91	8.72	5.31
9.4	9.52	9.42	6.00	4.85	2.05	2.38	2.96	4.54	0.57	0.29	9.11	8.91	5.43
9.6	9.72	9.62	6.13	4 96	2.10	2.44	3.02	4.63	0.59	0.29	9.30	9.10	5.54
9.8	9.92	9.82	6.26	5.06	2.14	2.49	3.08	4.73	0.60	0.30	9.49	9.29	5.66
10.0	10.126	10.025	6.385	5.163	2.183	2.537	3.144	4.825	0.6108	0.305	9.688	9.476	5.774

TABLE IV. Pallet with Equidistant Lockings—Club Wheel.

1	2	3	4	5	6	7		8		9		10	11	12	13	14	15
Diameter of wheel circle.			Circles of pallet.			Lifting circles for the total angle of movement.						Height of segment.	Breadth of pallet-arm.	Breadth of wheel-teeth before inclining.	Tangent circles for the inclination of teeth.		Distance of centers.
Primitive	Outer		Locking.	Outer.	Inner	8°		10°		12°					8°	10 & 12°	
	Real	Meas'd															
1.00.	1.0126	1.0025	0.5774	0.69956	0.45524	0.176	0.2621	0.2061	0.304	0.2584	0.3724	0.5113	0.06108	0.0305	0.9688	0.9476	0.5774
5.0	5.06	5.01	2.89	3.50	2.28	0.88	1.31	1.03	1.52	1.29	1.86	2.56	0.31	0.15	4.84	4.74	2.89
5.2	5.27	5.21	3.00	3.64	2.37	0.92	1.36	1.07	1.58	1.34	1.94	2.66	0.32	0.16	5.04	4.93	3.00
5.4	5.47	5.41	3.12	3.78	2.46	0.95	1.42	1.11	1.64	1.40	2.01	2.76	0.33	0.16	5.23	5.12	3.12
5.6	5.67	5.61	3.23	3.92	2.55	0.99	1.47	1.15	1.70	1.45	2.09	2.86	0.34	0.17	5.43	5.31	3.23
5.8	5.87	5.81	3.35	4.06	2.64	1.02	1.52	1.20	1.76	1.50	2.16	2.97	0.35	0.18	5.62	5.50	3.35
6.0	6.08	6.02	3.46	4.20	2.73	1.06	1.57	1.24	1.82	1.55	2.23	3.07	0.37	0.18	5.81	5.69	3.46
6.2	6.28	6.22	3.58	4.34	2.82	1.09	1.63	1.28	1.88	1.60	2.31	3.17	0.38	0.19	6.01	5.88	3.58
6.4	6.48	6.42	3.70	4.48	2.91	1.13	1.68	1.32	1.95	1.65	2.38	3.27	0.39	0.20	6.20	6.06	3.70
6.6	6.68	6.62	3.81	4.62	3.00	1.16	1.73	1.36	2.01	1.71	2.46	3.37	0.40	0.20	6.39	6.25	3.81
6.8	6.89	6.82	3.93	4.76	3.10	1.20	1.78	1.40	2.07	1.76	2.53	3.48	0.42	0.21	6.59	6.44	3.93
7.0	7.09	7.02	4.04	4.90	3.19	1.23	1.83	1.44	2.13	1.81	2.61	3.58	0.43	0.21	6.78	6.63	4.04
7.2	7.29	7.22	4.16	5.04	3.28	1.27	1.89	1.48	2.19	1.86	2.68	3.68	0.44	0.22	6.98	6.82	4.16
7.4	7.49	7.42	4.27	5.18	3.37	1.30	1.94	1.53	2.25	1.91	2.76	3.78	0.45	0.23	7.17	7.01	4.27
7.6	7.70	7.62	4.39	5.32	3.46	1.34	1.99	1.57	2.31	1.96	2.83	3.89	0.46	0.23	7.36	7.20	4.39
7.8	7.90	7.82	4.50	5.46	3.55	1.37	2.04	1.61	2.37	2.02	2.90	3.99	0.48	0.24	7.56	7.39	4.50
8.0	8.10	8.02	4.62	5.60	3.64	1.41	2.10	1.65	2.43	2.07	2.98	4.09	0.49	0.24	7.75	7.58	4.62
8.2	8.30	8.22	4.73	5.74	3.73	1.44	2.15	1.69	2.49	2.12	3.05	4.19	0.50	0.25	7.94	7.77	4.73
8.4	8.51	8.42	4.85	5.88	3.82	1.48	2.20	1.73	2.55	2.17	3.13	4.29	0.51	0.26	8.14	7.96	4.85
8.6	8.71	8.62	4.97	6.02	3.92	1.51	2.25	1.77	2.61	2.22	3.20	4.40	0.53	0.26	8.33	8.15	4.97
8.8	8.91	8.82	5.08	6.16	4.01	1.55	2.31	1.81	2.68	2.27	3.28	4.50	0.54	0.27	8.53	8.34	5.08
9.0	9.11	9.02	5.20	6.30	4.10	1.58	2.36	1.85	2.74	2.33	3.35	4.60	0.55	0.27	8.72	8.53	5.20
9.2	9.32	9.22	5.31	6.44	4.19	1.62	2.41	1.90	2.80	2.38	3.43	4.70	0.56	0.28	8.91	8.72	5.31
9.4	9.52	9.42	5.43	6.58	4.28	1.65	2.46	1.94	2.86	2.43	3.50	4.81	0.57	0.29	9.11	8.91	5.43
9.6	9.72	9.62	5.54	6.72	4.37	1.69	2.52	1.98	2.92	2.48	3.58	4.91	0.59	0.29	9.30	9.10	5.54
9.8	9.92	9.82	5.66	6.86	4.46	1.72	2.57	2.02	2.98	2.53	3.65	5.01	0.60	0.30	9.49	9.29	5.66
10.0	10.126	10.025	5.774	6.9956	4.5524	1.76	2.621	2.061	3.04	2.584	3.724	5.113	0.6108	0.305	9.688	9.476	5.774

tables without presenting any difference that could be measured with even very delicate instruments.

LOCKING CIRCLE.

The calculation of the locking circle is the same as for the ratchet wheel pallet, and based upon the same diameter of wheel $= 1$ and the same angle of $30°$; the size of the circle is also the same $= 0.5774$.

OUTER AND INNER CIRCLE OF PALLET.

These sizes differ from those in Tables I and II, because the half of the space between two teeth is divided into $1\frac{1}{2}°$ of drop, $3\frac{1}{2}°$ breadth of wheel tooth and $7°$ breadth of pallet arm. This latter must be calculated first, before finding the numbers of outer and inner circle.

The circumference of the primitive circle of the wheel is:

$$1 \,.\, 3.1416 = 3.1416.$$

The arc of $7°$ of this circumference is

$$= \frac{3.1416 \,.\, 7}{360} = \frac{21.9912}{360} = 0.06108.$$

In Table III the diameter of outer circle is

= the diameter of locking circle	=	0.5774
+ the breadth of pallet arm	=	0.06108
		0.63848

and the diameter of inner circle is

= the diameter of locking circle	=	0.5774
— the breadth of pallet arm	=	0.06108
		0.51632

In Table IV the diameter of the outer circle is

= the diameter of locking circle	=	0.5774
+ double the breadth of pallet arm	=	0.12216
		0.69956

and the diameter of inner circle

= the diameter of locking circle	=	0.5774
— double the breadth of pallet arm	=	0,12216
	=	0.45524

LIFTING CIRCLES. CIRCULAR PALLET.

Total angle of movement $8°$

Locking angle $= 1°$

Lifting angle of wheel tooth $= 2°$

Lifting angle of pallet $= 5°$

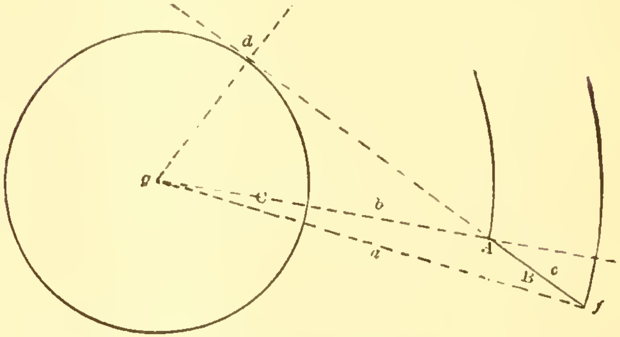
$a = 0.3192$ (radius of outer circle)

$b = 0.2582$ (radius of inner circle)

$C = 5°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 2° \, 30' = 87° \, 30'$$

$$\text{tang.} \left(\frac{A-B}{2}\right) \quad \frac{a-b}{a+b} \cdot \text{cotang.} \frac{C}{2}$$



$$= \frac{0.3192 - 0.2582}{0.3192 + 0.2582} \cdot \text{cotang } 2° \, 30'$$

$$= \frac{0.061}{0.5774} \cdot \text{cotang. } 2° \, 30'$$

$$= 0.1056 \,.\, 2.2904 = 2.4187$$

$$\frac{A-B}{2} = 67° \, 30'$$

$$B = 87° \, 30' - 67° \, 30' = 20°$$

$$g\,d = a \,.\, \sin B = 0.3192 \,.\, \sin 20°$$

$$= 0.3192 \,.\, 0.342$$

$$= 0.109166$$

Diameter of lifting circle $=$
$2 \,.\, gd = 2 \,.\, 0.109166 = 0.2183.$

Total angle of movement $= 10°$
Locking angle $= 1\frac{1}{2}°$
Lifting angle of wheel $= 2\frac{1}{2}°$
Lifting angle of pallet $= 6°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 3° = 87°$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b}.\ \text{cotang.}\ \frac{C}{2}$$

$$= 0.1056\ .\ \text{cotang.}\ 3° = 0.1056\ .\ 1.9081 = 2.01495$$

$$\frac{A-B}{2} = 63°\ 35'$$

$$B = 87° - 63°\ 35' = 23°\ 25'$$

$$gd = a\ .\ \sin B = 0.3192\ .\ \sin\ 23°\ 25'$$
$$= 0.3192\ .\ 0.3974 = 0.12685$$

Diameter of lifting circle $= 2\ .\ gd$
$= 2\ .\ 0.12685 = 0.2537$

Total angle of movement $= 12\frac{1}{2}$
Locking angle $= 1\frac{1}{2}°$
Lifting angle of wheel $= 2\frac{1}{2}°$
Lifting angle of pallet $= 8°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 4° = 86'$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b}\ \text{cotang.}\ \frac{C}{2}$$
$$= 0.1056\ .\ \text{cotang}\ .\ 4°$$
$$= 0.1056\ .\ 14.301 = 1.5102$$

$$\frac{A-B}{2} = 56°\ 30'$$

$$B = 86° - 56°\ 30' = 29°\ 30'$$

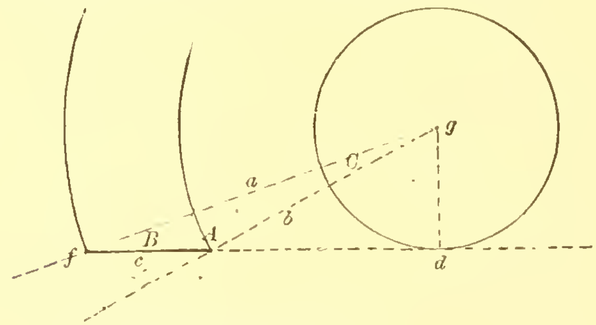
$$gd = a\ .\ \sin B = 0.3192\ .\ \sin 29°\ 30'$$
$$= 0.3192\ .\ 0.4924. = 0.157174.$$

Diameter of lifting circle $= 2\ .\ gd$
$= 2\ .\ 0.157174 = 0.3144$

LIFTING-CIRCLES, TABLE IV.—PALLET WITH EQUIDISTANT LOCKINGS.

For greater simplification of the matter, we shall calculate the lifting circles of the first arm for all the three angles at first, because the greater part of the coefficients are the same for all.

LIFTING CIRCLES OF THE FIRST PALLET ARM.



Angle of movement $= 8°$
Lifting angle of pallet $= 5°$
$a = 0{,}2887$ (radius of locking-circle)
$b = 0{,}2279$ (radius of inner circle)
$C = 5°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 2°\ 30' = 87°\ 30'$$

$$\text{tang}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b}.\ \text{cotang.}\ \frac{C}{2}$$
$$= \frac{0{,}2887 - 0{,}2276}{0{,}2887 + 0{,}2276}.\ \text{cotang.}\ 2°\ 30'$$

$$= \frac{0,0611}{0,5163} . \text{ cotang. } 2° \, 30'$$

$$= 0,1183 \, . \, 22,904 = 2.7095$$

$$\frac{A-B}{2} = 69° \, 45'$$

$$B = 87° \, 30' - 69° \, 45' = 17° \, 45'$$

$$g \, d = a \, . \, \sin B \, . = 0,2887 \, . \, 0,3049 \, .$$

$$= 0,088025$$

Diameter of lifting-circle $= 2 \, g \, d$

$$= 2 \, . \, 0,088025 = 0,176$$

Angle of movement = 10°

Lifting-angle of pallet = 6°

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 3° = 87°$$

$$\text{tang} \, . \left(\frac{A-B}{2}\right) = 0,1183 \, . \text{ cotang. } 3°$$

$$= 0,1183 \, . \, 19,081 \, . = 2,2573 \, .$$

$$\frac{A-B}{2} = 66° \, 5'$$

$$B = 87° - 66° \, 5' = 20° \, 55' \, .$$

$$g \, d = a \, . \, \sin B \, . = 0,2887 \, . \, 0,357 \, . = 0,10307 \, .$$

Diameter of lifting-circle $= 2 \, . \, g \, d$

$$= 2 \, . \, 0,10307 = 0,2061$$

Angle of movement = 12°.

Lifting-angle of the pallet = 8°

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 4° = 86° -$$

$$\text{tang} \left(\frac{A-B}{2}\right) = 0,1183 \, . \text{ cotang. } 4°$$

$$= 0,1183 \, . \, 14,301 = 1,6918 \, .$$

$$\frac{A-B}{2} = 59° \, 25'$$

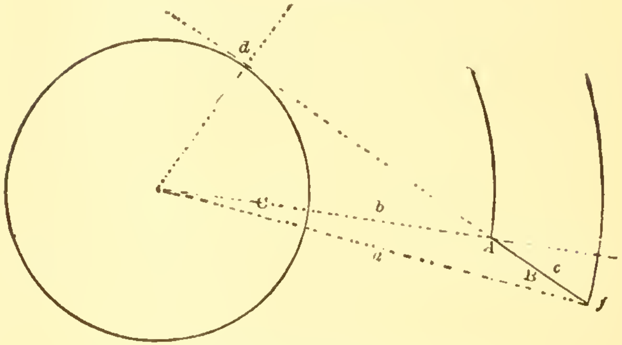
$$B = 86° - 59° \, 25' = 26° \, 35'$$

$$g \, d = a \, . \, \sin B = 0,2887 \, . \, 0,4475 = 0,12919 \, .$$

Diameter of lifting-circle $= 2 \, g \, d$

$$= 2 \, . \, 0,12919 = 0,2584 \, .$$

LIFTING CIRCLES OF SECOND PALLET ARM.



Angle of movement = 8°

$a = 0,34978$ (radius of outer circle)

$b = 0,2887$ (radius of locking circle)

$$C = 5°$$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 2° \, 30' = 87° \, 30'$$

$$\text{tang} \left(\frac{A-B}{2}\right) = \frac{0,34978 - 0,2887}{0,34978 + 0,2887} . \text{ cotang. } \frac{C}{2}$$

$$= \frac{0,06108}{0,63848} . \text{ cotang. } 2° \, 30'$$

$$= 0,09568 \, . \, 22.904$$

$$= 2,19145 \, .$$

$$\frac{A-B}{2} = 65° \, 30'$$

$$B = 87° \, 30' - 65° \, 30' = 22°$$

$$g \, d = a \, . \, \sin B = 0,34978 \, . \, 0,3746 \, . = 0,131028$$

Diameter of lifting circle $= 2 \,.\, g\,d$
$= 2 \,.\, 0{,}131028 = 0{,}2621 \,.$

Angle of movement $= 10°$
Lifting angle of the pallet $= 6°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 3° = 87°.$$

$$\text{tang}\left(\frac{A-B}{2}\right) = 0{,}09568 \,.\, \text{cotang } 3°$$

$$= 0{,}09568 \,.\, 19{,}081 = 1{,}82557 \,.$$

$$\frac{A-B}{2} = 61°\ 15'$$

$$B = 87° - 61°\ 15' = 25°\ 45'$$

$$g\,d = a \,.\, \sin B \,. = 0{,}34978 \,.\, 0{,}4345 \,. = 0{,}151979$$

Diameter of lifting circle $= 2 \,.\, g\,d$
$= 2 \,.\, 0{,}151979 = 0{,}304$

Angle of movement $= 12°$
Lifting angle of the pallet $= 8°$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 4° = 86°$$

$$\text{tang}\left(\frac{A-B}{2}\right) = 0{,}09568 \,.\, \text{cotang } 4°$$

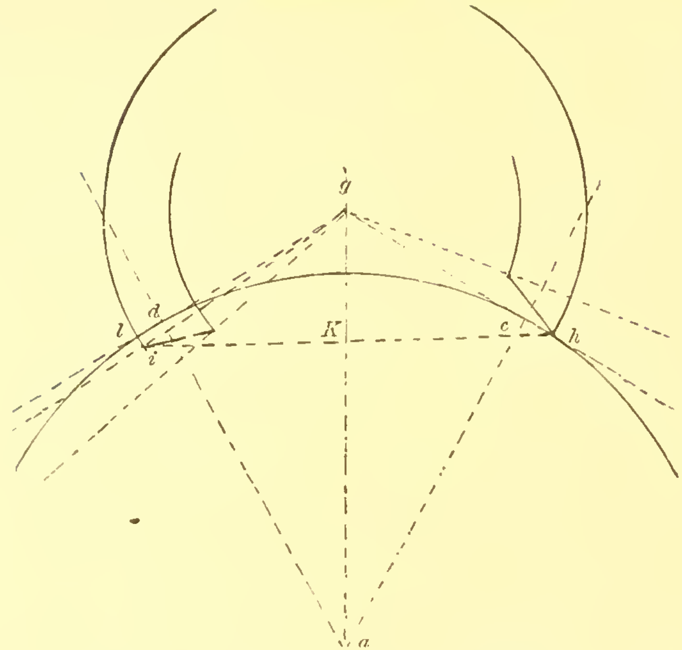
$$= 0{,}09568 \,.\, 14{,}301 = 1{,}3683$$

$$\frac{A-B}{2} = 53°\ 50'$$

$$B \,. = 86° - 53°\ 50' = 32°\ 10'$$

$$g\,d = a \,.\, \sin \,.\, B \,. = 0{,}34978 \,.\, 0{,}5324 \,. = 0{,}1862$$

Diameter of lifting circle $= 2 \,.\, g\,d$
$= 2 \quad 0{,}1862 = 0{,}3724 \,.$



$g\,h = g\,i = 0.31925$ (radius of outer circle)
$< h\,g\,i = 118°\ 30'$ (by construction)

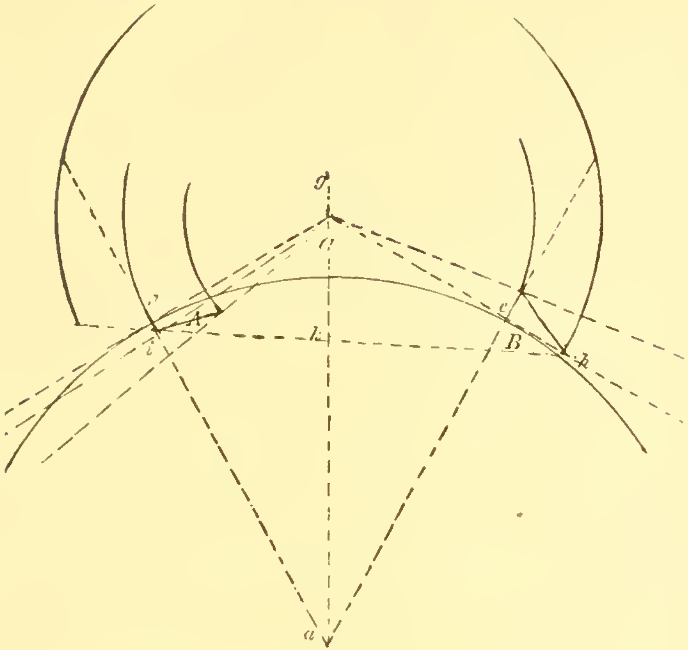
$$< g\,h\,i = < g\,i\,h = \frac{180° - 118°\ 30'}{2} = \frac{61°\ 30'}{2} = 30°\ 45'$$

Of the rectangular triangle $g\,h\,k$ we know ·

$g\,h = 0.31925 \,.$
$< g\,h\,i = 30°\ 45'$
$g\,k = g\,h \,.\, \sin \,.\, g\,h\,i \quad = 0.31925 \ \sin 30°\ 45'$
$= 0.31925 \,.\, 0.5113 = 0.16323 \,.$

The sum of the radius of outer circle	$= 0.31925$
and the line $g\,k$	$= 0.16323 \,.$
is the height of segment	$= 0.48248$

TABLE IV.—PALLET WITH EQUIDISTANT LOCKINGS.



$g\,i$ = radius of locking circle = 0.2887 .
$g\,h$ = radius of outer circle = 0.34978 .

$< i\,g\,h = 118° 30'$

For brevity we call:

$g\,h - a$ and the angles opposite to them:
$g\,i - b$ A, B and C.
$h\,i - e$.

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - \frac{118° 30'}{2}$$
$$= 90° - 59° 15' = 30° 45'$$

$$\text{tang}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b} \,.\, \text{cotang.} \frac{C}{2}$$
$$= \frac{0.3498 - 0.2887}{0.3498 + 0.2887} \,.\, \text{cotang. } 59° 15'$$
$$= \frac{0.0611}{0.6385} \,.\, 0.595$$
$$= 0.09568 \,.\, 0.595 = 0.05693 \,.$$

$$\frac{A-B}{2} = 3° 15'$$

$$B = 30° 45' - 3° 15' = 27° 30'$$

In the rectangle $g\,h\,k$ there is:

$g\,h = 0.3498$
$B = 27° 30'$
$g\,k = g\,h \,.\, \sin B \,. = 0.3498 \,.\, \sin \,.\, 27° 30'$
$= 0.3498 \,.\, 0.4617 = 0.1615$,

The sum of the radius of outer circle = 0.3498
+ the line $g\,k$ = 0.1615
is the height of segment = 0.5113

The breadth of pallet arms is the same for both tables, and it has already been mentioned that it is = 7° of the wheel's circumference:

$$\frac{1 \,.\, 3.1416 \,.\, 7}{360} = 0.06108 \,.$$

The breadth of wheel teeth (before inclining) having been fixed to $3\frac{1}{2}°$ of the wheel circle, is accordingly half the breadth of pallet arm = 0.03054

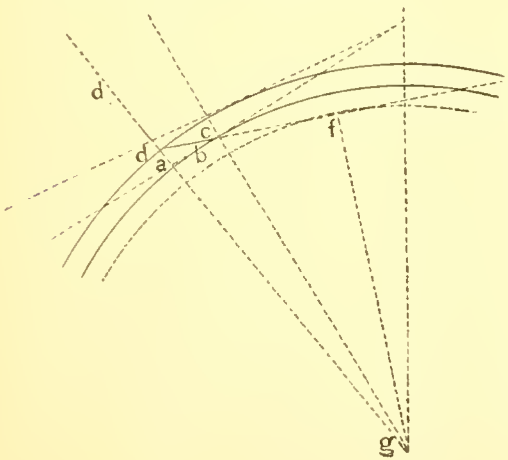
The tangent circles for the inclined planes of the teeth are also the same in both the tables, but it must be remembered here, that for the sake of better respective proportion, it has been found advisable to make the teeth for an escapement of 8° movement lift only 2°, while the 2 other angles spoken of in these tables will be better arranged with a lifting of $2\frac{1}{2}°$ at the teeth.

Therefore there are two columns of tangent circles in each table. It may be observed here, that it would not derange the other proportions, if an escapement should be executed to give 8°, as the table prescribes it, giving to the teeth a lifting angle of $2\frac{1}{2}°$. The only effect of the change would be an augmentation of the total angle of movement from 8 to $8\frac{1}{2}°$. For escapements of 10 and 12° of movement, it is also allowed to give the wheel teeth a lifting angle of but 2°, without altering in any way the correctness of the other proportions, so that the only effect of the change will be a diminishing of the total lifting angle by $\frac{1}{2}$ degree.

The calculation of the tangent circles in question is the following:

The inclined part of the tooth, projecting beyond the primitive radius, presents a small rectangular triangle, of which we know:

$b = 0.03054$ (breadth of wheel tooth)



$a = 0.0126$ (difference of outer and primitive radius of wheel)

$$\text{tang. } B. = \frac{b}{a} = \frac{0.03054}{0.0126} = 2.4238.$$

$$B = 67° \ 35'$$

We prolong the line c and draw a perpendicular line to it passing through the centre of the wheel.

The rectangular triangle $d\ g\ f$ contains the known parts:

$d\ g =$ radius of outer wheel circle $= 0.5126$.

$< B = 67° \ 35'$

$g f = d g \,.\, \sin B. = 0.5126 \,.\, 0.9244 = 0.4738$

Diameter of tangent circle $= 2 \,.\, g f$

$= 2 \,.\, 0.4738 = 0.9476$

For the angle of lifting $= 2°$, there is:

$b = 0.03054$

$a = 0.010075$

$$\text{tang. } B. = \frac{b}{a} = \frac{0.03054}{0.001075} = 3.03127.$$

$$B. = 71° \ 45'$$

$g f = g\ d \,.\, \sin B = 0.510075 \,.\, 0.9497 = 0.4844$

Diameter of tangent circle $= 2\ g\ f$

$= 2 \,.\, 0.4844 = 0.9688$

The primitive diameter of the club-wheel being the same (1,00) as in Tables 1 and 2, the wheel having the same number of teeth and consequently the same scaping angle, the distance of centres must be the same as in those tables $= 0.5774$.

Explanation of Table V.

This table gives the proportions for the improved club wheel escapement with circular pallet, proposed in Chapter V and illustrated in Diagram VIII.

There are many escapement makers who are very fond of circular pallets, though they are defective in principle.

TABLE V. Improved Circular Pallet Escapement with Club Wheel. (Diagram 8.)

1	2	3	4	5	6	7	8	9	10	11
Diameter of wheel circle.			Circles of pallet.		Lifting-circle for the angle of movement 10°	Height of segment.	Breadth of pallet-arm.	Breadth of wheel-teeth before inclining.	Tangent-circle for inclined planes of teeth.	Distance of centres.
	Outer.									
Primitive. 1.00	Real 1.0454	Measured 1.0349	Outer 0.6210	Inner 0.5338	0.243	0.4693	0.0436	0.048	0.9448	0.5774
5.00	5.23	5.17	3.11	2.67	1.22	2.35	0.22	0.24	4.72	2.89
5.2	5.44	5.38	3.23	2.78	1.26	2.44	0.23	0.25	4.91	3.00
5.4	5.65	5.58	3.35	2.88	1.31	2.53	0.24	0.26	5.10	3.12
5.6	5.85	5.79	3.48	2.99	1.36	2.63	0.24	0.27	5.29	3.23
5.8	6.06	6.00	3.60	3.10	1.41	2.72	0.25	0.28	5.48	3.35
6.0	6.27	6.21	3.73	3.20	1.46	2.82	0.26	0.29	5.67	3.46
6.2	6.48	6.42	3.85	3.31	1.51	2.91	0.27	0.30	5.86	3.58
6.4	6.69	6.62	3.97	3.42	1.56	3.00	0.28	0.31	6.05	3.70
6.6	6.90	6.83	4.10	3.52	1.61	3.10	0.29	0.32	6.24	3.81
6.8	7.11	7.04	4.22	3.63	1.65	3.19	0.30	0.33	6.42	3.93
7.0	7.32	7.24	4.35	3.74	1.70	3.29	0.31	0.34	6.61	4.04
7.2	7.53	7.45	4.47	3.84	1.75	3.38	0.31	0.35	6.80	4.16
7.4	7.74	7.66	4.60	3.95	1.80	3.47	0.32	0.36	6.99	4.27
7.6	7.95	7.87	4.72	4.06	1.85	3.57	0.33	0.36	7.18	4.39
7.8	8.15	8.07	4.84	4.16	1.90	3.66	0.34	0.37	7.37	4.50
8.0	8.36	8.28	4.97	4.27	1.94	3.75	0.35	0.38	7.56	4,62
8.2	8.57	8.49	5.09	4.38	1.99	3.85	0.36	0.39	7.75	4.73
8.4	8.78	8.69	5.22	4.48	2.04	3.94	0.37	0.40	7.94	4.85
8.6	8.99	8.90	5.34	4.59	2.09	4.04	0.37	0.41	8.13	4.97
8.8	9.20	9.11	5.46	4.70	2.14	4.13	0.38	0.42	8.31	5.08
9.0	9.41	9.31	5.59	4.80	2.19	4.22	0.39	0,43	8.50	5.20
9.2	9.62	9.52	5.71	4.91	2.24	4.32	0.40	0.44	8.69	5.31
9.4	9.83	9.73	5.84	5.02	2.28	4.41	0.41	0.45	8.88	5.43
9.6	10.04	9.94	5.96	5.12	2.33	4.51	0.42	0.46	9.07	5.54
9.8	10.24	10.14	6.09	5.23	2.38	5.60	0.43	0.47	9.26	5.66
10.0	10.454	10.349	6.21	5.338	2.43	4.693	0.436	0.48	9.448	5.774

When a ratchet wheel is employed, there is nothing to be done against this deficiency. but with the club wheel the possibility of diminishing it exists, and thus I see no reason why this should not be done. The pallet arms becoming much smaller by this arrangement, the locking-circles, accordingly, are but very little out of their natural place, and this circular pallet is nearly as correct as one with equidistant lockings.

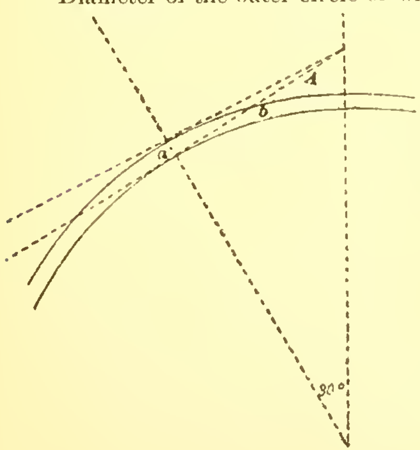
The arrangement illustrated by Diagram VII has an angle of movement of 10° from drop to drop, leaving after subtraction of the locking-angle of $1\frac{1}{2}°$ a lifting-angle of $8\frac{1}{2}°$, of which $4\frac{1}{2}°$ are performed by the wheel-teeth, and 4° by the pallet. The space of 12° at the wheel's primitive circumference is divided accordingly, so that the breadth of the tooth is $5\frac{1}{2}°$ and that of the pallet arm 5°, thus leaving $1\frac{1}{2}°$ of drop.

CALCULATIONS—COLUMN ONE.

Diameter of the primitive circle of the wheel = 1.

COLUMN TWO.

Diameter of the outer circle of wheel.



b =0.2887 (radius of locking-circle)

A=4° 30′

$a = b$. tang. A

=0.2887 . tang. $4\frac{1}{2}°$

=0.2887 . 0.0787 .

=0.0227 .

Outer diameter = $1+2\,a$

= 1+2 . 0,0227 =1+0,0454 = 1,0454

COLUMN 3.

Measured diameter = 1.0454 . 0.99

= 1.0349 .

COLUMN FOUR.

The diameter of outer circle of pallet =

the diameter of the locking-circle = 0.5774 .

\+ the breadth of pallet-arm = 0.0436 .

0.6210

COLUMN FIVE.

The diameter of inner pallet-circle =

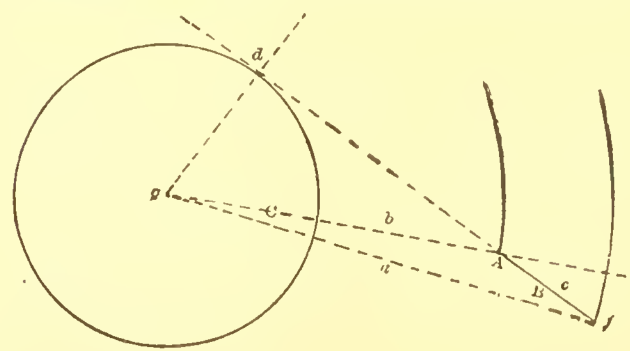
the radius of the locking-circle = 0.5774

— the breadth of pallet-arm = 0.0436 .

0.5338

COLUMN SIX.

The lifting-circle has been calculated merely for the angle of movement of 10°, in order to simplify the table.



$a = 0.3105$ (radius of outer circle)
$b = 0.2669$ (radius of inner circle.)

$$C = 4°$$

$$\frac{A+B}{2} = 90° - \frac{C}{2} = 90° - 2° = 88°$$

$$\text{tang.}\left(\frac{A-B}{2}\right) = \frac{a-b}{a+b} \cdot \text{ cotang. } \frac{C}{2}$$

$$= \frac{0.3105 - 0.2669}{0.3105 + 0.2669} \cdot \text{ cotang. } 2°$$

$$= \frac{0.0436}{0.5774} \cdot \text{ cotang. } 2°$$

$$= 0{,}0755.\ 28{,}636. = 2.162$$

$$\frac{A-B}{2} = 65°\ 10'$$

$B = 88° - 65°\ 10' = 22°\ 50'$

$g\,d = a\ .\ \sin B. = 0.3105.9.3881. = 0.1215.$

Diameter of lifting-circle $= 2\ .\ gd.$

$= 2.0.1215 = 0.243.$

COLUMN SEVEN.

The height of segment is to be found in the same way as it has been done in the corresponding cases referring to Tables I and IV.

$gh = gi = 0.3105$ (radius of outer circle.)

$< ghi = 118°\ 30'$ (by construction.)

$$< ghi = < gih = \frac{180° - 118°\ 30'}{2} = \frac{61°\ 30'}{2}$$

$$= 30°\ 45'$$

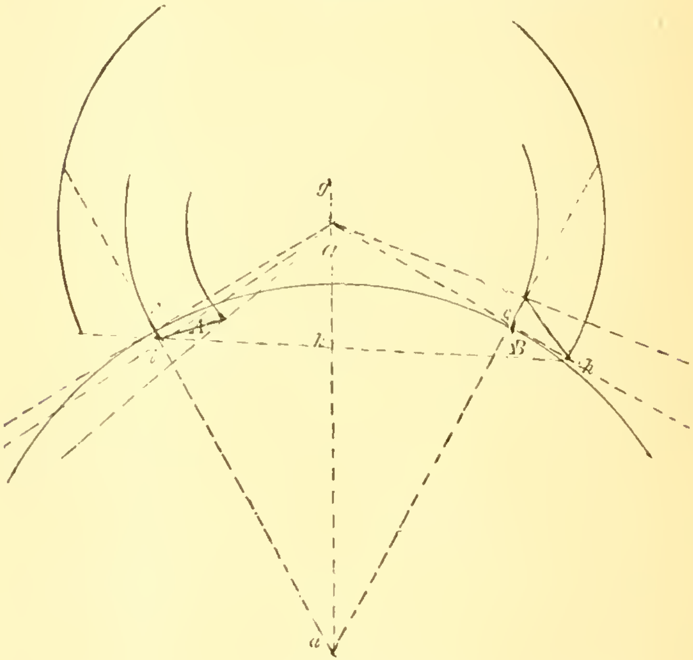
In the rectangular triangle ghk we know:

$gh = 0.3105.$

$< ghi = 30°\ 45'$

$gk = gh\ .\ \sin\ .\ 30°\ 45' = 0.3105\ .\ 0.5113\ . = 0.1588.$

The sum of the radius of the outer pallet circle $= 0.3105$
$+$ the line gk $= 0.1588.$
is the height of segment $= 0.4693.$



COLUMN EIGHT.

Breadth of pallet arm $= 5°$ of the primitive circle or wheel,

$$= \frac{3.1416.5}{360} = \frac{3.1416}{72} = 0.0436.$$

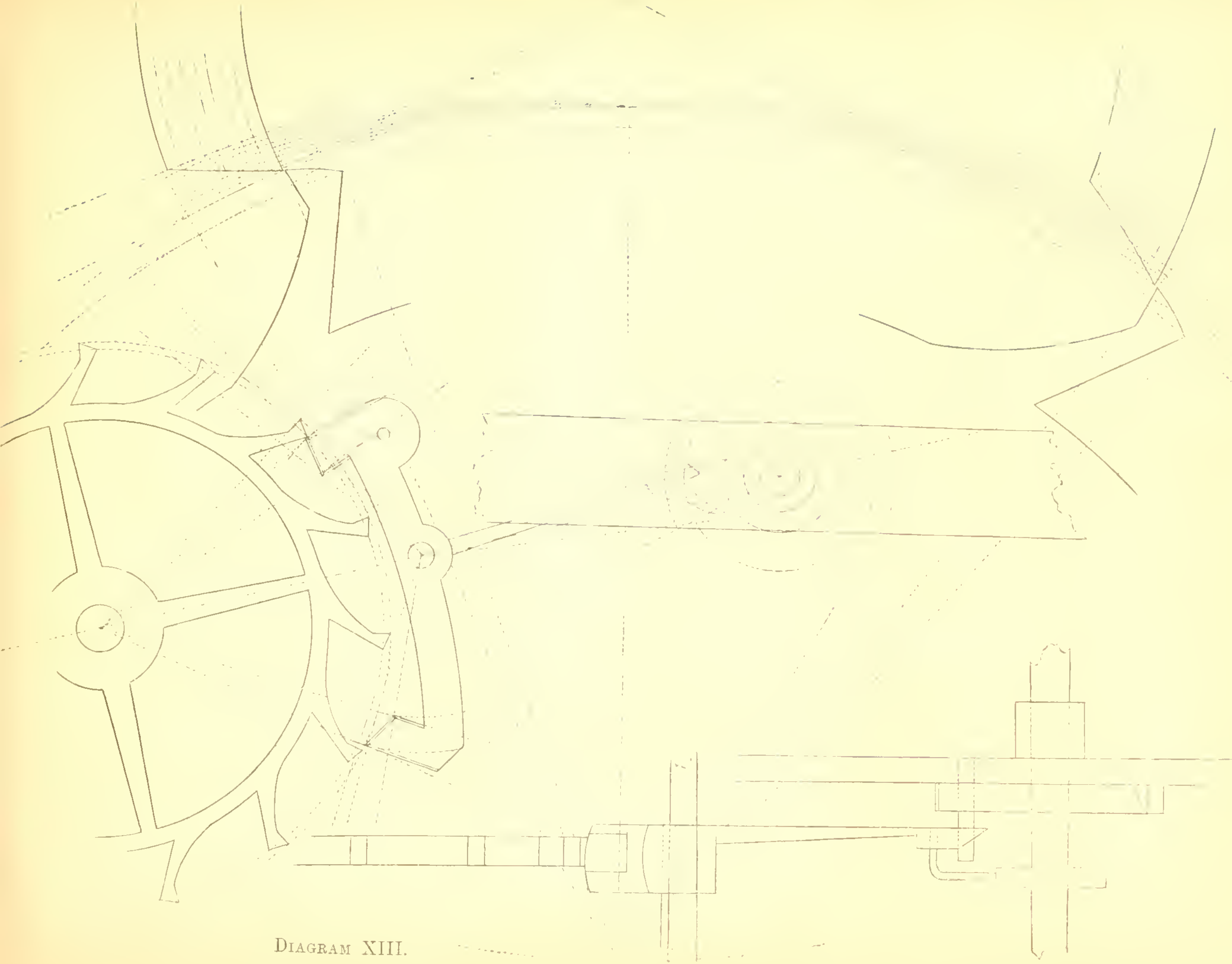


Diagram XIII.

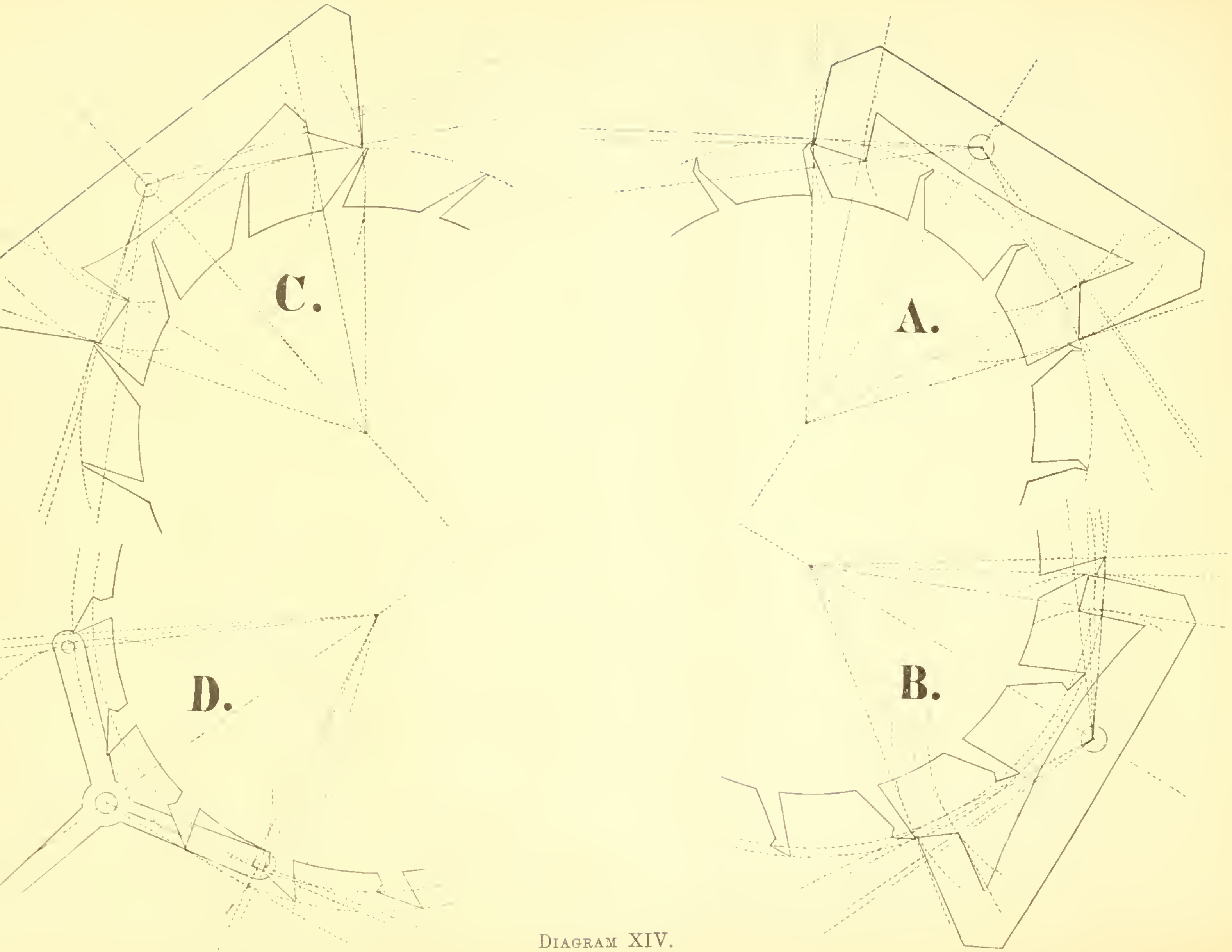


DIAGRAM XIV.

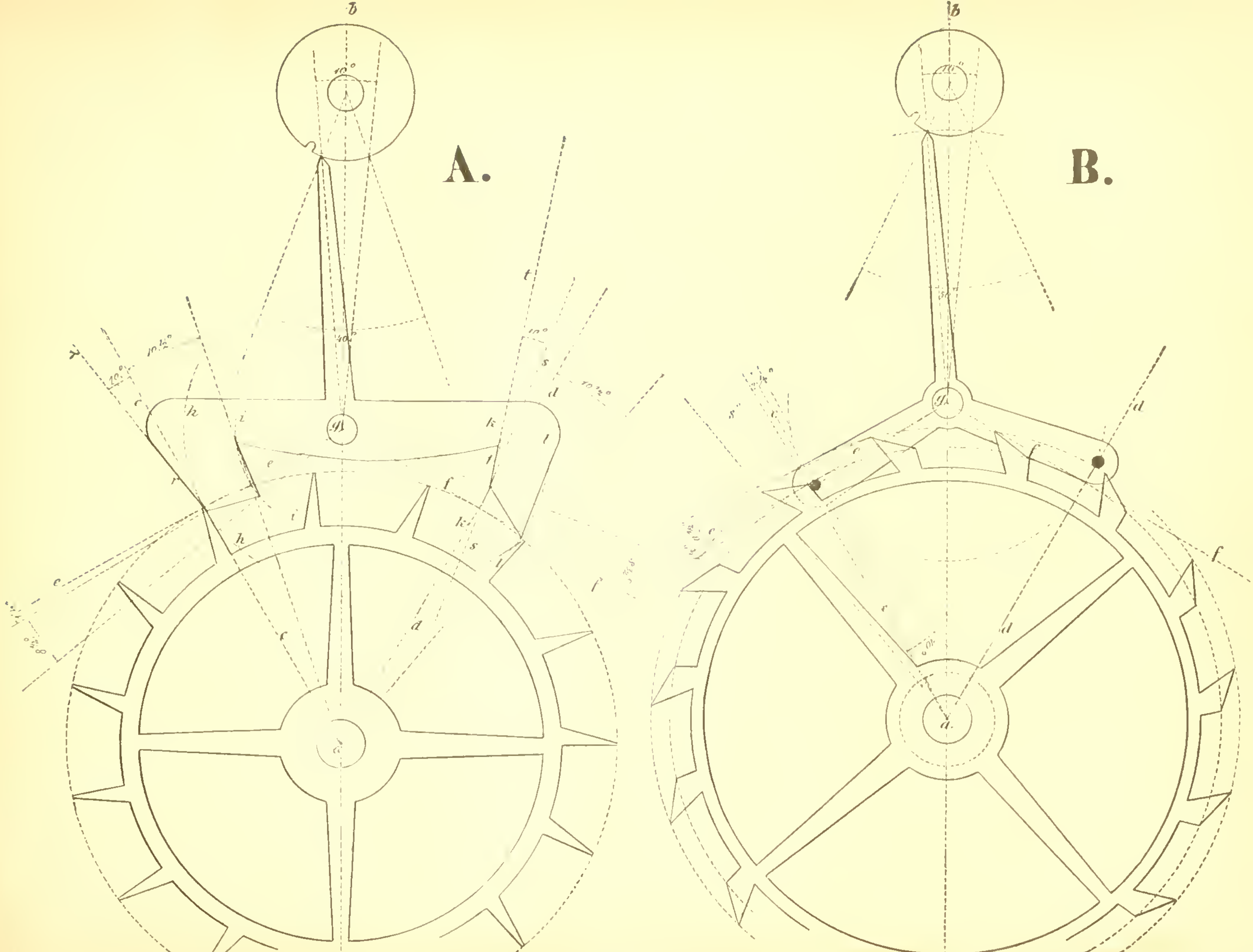


DIAGRAM XV.

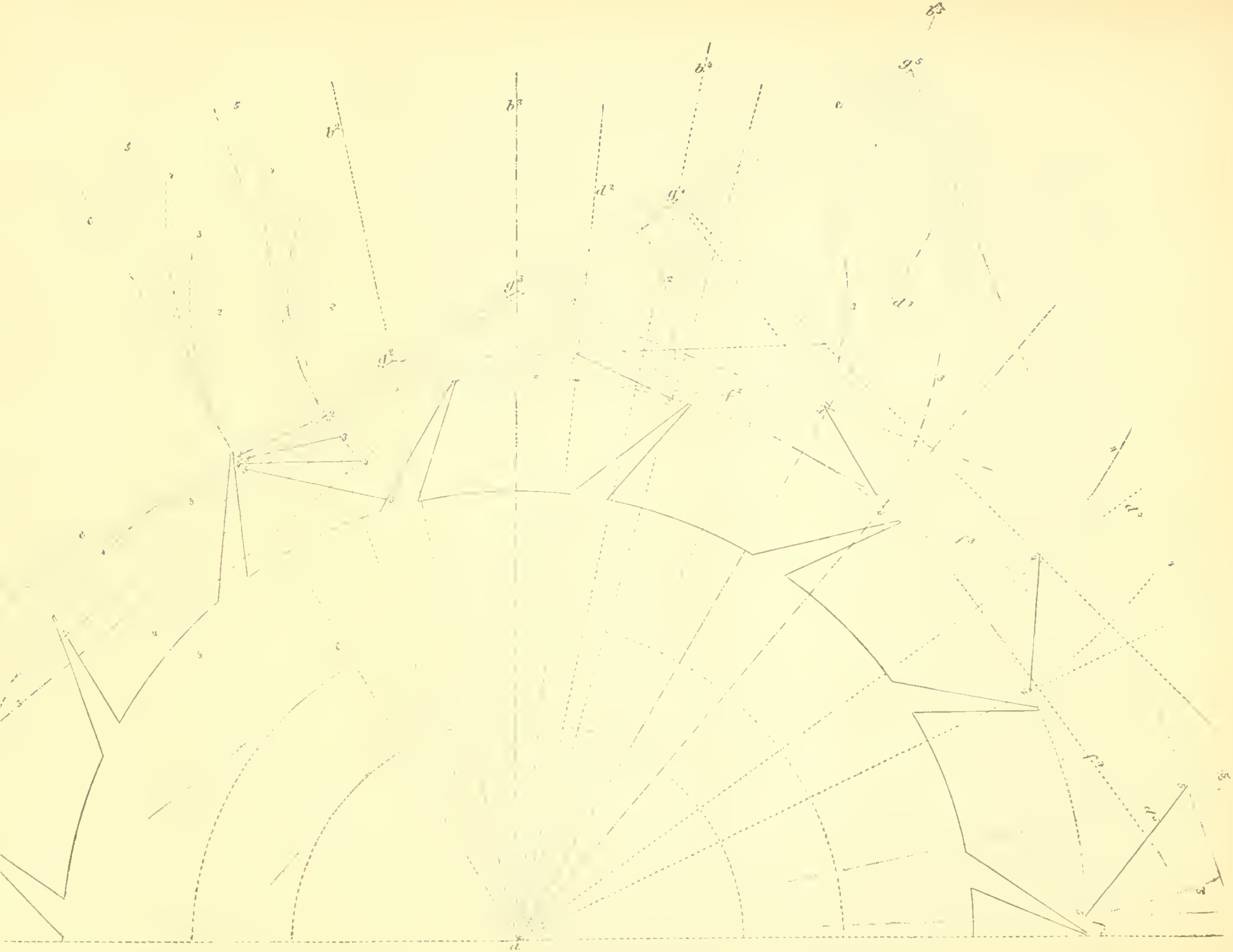


DIAGRAM XVI.

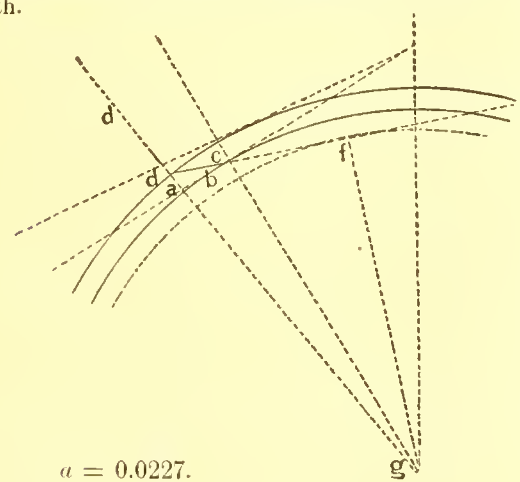
COLUMN NINE.

The breadth of the wheel teeth before making the inclined planes, measured at the primitive circle of the wheel, is

$$=\frac{3.1416.5.5^\circ}{360}=\frac{3.1416.1.1}{72}=\frac{3.45576}{72}=0.048\,.$$

COLUMN TEN.

The tangent circle for the inclined planes on the wheel teeth.



$a = 0.0227.$

$b = 0.048.$

$$\text{tang. } B. = \frac{b}{a} = \frac{0.048}{0.0227} = 2.1146.$$

$B = 64^\circ\ 40'$

In the rectangular triangle dgf there is:

$dg = 0.5227$. (radius of outer wheel circle)

$< B = 64^\circ\ 40'$

$gf = dg.\sin.B. = 0.5227.\sin 64^\circ\ 40'$

$= 0.5227.\ 0.9038$

$= 0.4724.$

Diameter of tangent circle $= 2.gf$

$= 2.0.4724 = 0.9448.$

COLUMN ELEVEN.

The distance of centres is equal to that of Tables I and IV.

Explanation of Table VI.

This table refers to the pin anchor, and though this construction is very rarely employed, and, I may say, very little known, I think it likely that some who have read the particulars of it in the fifth chapter might be desirous to try it for such purpose as it may be suitable. Therefore, and for greater completeness, a table of proportions of the pin anchor might be useful. Still, I have executed it in a simplified way, only referring to the angle of movement of 10°, this being about the average of the angles in use.

With the aid of this table an anchor of this kind will not be an object of difficult execution, as it requires no jewels, nor anything beyond the reach of every watchmaker's workshop.

COLUMNS ONE, TWO AND THREE.

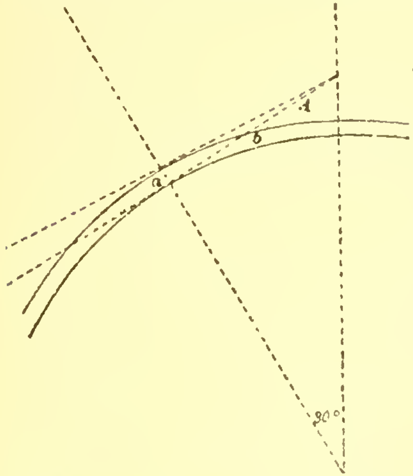
The primitive diameter is, as well as in all the preceding calculations, supposed to be = 1.

The outer diameter must be calculated according to the

TABLE VI. Pallet with Equidistant Lockings. Ratchet Wheel.

1	2	3	4	5	6	7	8	9	10	11
Diameter of wheel circle.			Thickness of the pins.	Breadth of teeth measured at the primitive circle.	Tangent. circle for the inclined planes.	Distance between the pins.	Distance measured across the outer sides of the pins.	Diameter of pin-circle (locking-circle.)	Height of triangle.	Distance of centres.
	Outer.									
Primitive. 1.00	Real 1.0658	Measured 1.055	0.0218	0.0698	0.9369	0.5171	0.5389	0.5774	0.1393	0.5774
5.0	5.33	5.28	0.11	0.35	4.68	2.59	2.70	2.89	0.70	2.89
5.2	5.54	5.49	0.11	0.36	4.87	2.69	2.80	3.00	0.72	3.00
5.4	5.76	5.70	0.12	0.38	5.06	2.79	2.91	3.12	0.75	3.12
5.6	5.97	5.91	0.12	0.39	5.25	2.90	3.02	3.23	0.78	3.23
5.8	6.18	6.12	0.13	0.40	5.43	3.00	3.13	3.35	0.81	3.35
6.0	6.39	6.33	0.13	0.42	5.62	3.10	3.23	3.46	0.84	3.46
6.2	6.61	6.54	0.14	0.43	5.81	3.21	3.34	3.58	0.86	3.58
6.4	6.82	6.75	0.14	0.45	6.00	3.31	3.45	3.70	0.89	3.70
6.6	7.03	6.96	0.14	0.46	6.18	3.41	3.56	3.81	0.92	3.81
6.8	7.25	7.17	0.15	0.47	6.37	3.52	3.67	3.93	0.95	3.93
7.0	7.46	7.39	0.15	0.49	6.56	3.62	3.77	4.04	0.98	4.04
7.2	7.67	7.60	0.16	0.50	6.75	3.72	3.88	4.16	1.00	4.16
7.4	7.89	7.81	0.16	0.52	6.93	3.83	3.99	4.27	1.03	4.27
7.6	8.10	8.02	0.17	0.53	7.12	3.93	4.10	4.39	1.06	4.39
7.8	8.31	8.23	0.17	0.54	7.31	4.03	4.20	4.50	1.09	4.50
8.0	8.53	8.44	0.17	0.56	7.50	4.14	4.31	4.62	1.11	4.62
8.2	8.74	8.65	0.18	0.57	7.68	4.24	4.42	4.73	1.14	4.73
8.4	8.95	8.86	0.18	0.59	7.87	4.34	4.53	4.85	1.17	4.85
8.6	9.17	9.07	0.19	0.60	8.06	4.45	4.64	4.97	1.20	4.97
8.8	9.38	9.28	0.19	0.61	8.24	4.55	4.74	5.08	1.23	5.08
9.0	9.59	9.50	0.20	0.63	8.43	4.65	4.85	5.20	1.25	5.20
9.2	9.81	9.71	0.20	0.64	8.62	4.76	4.96	5.31	1.28	5.31
9.4	10.02	9.92	0.20	0.66	8.81	4.86	5.07	5.43	1.31	5.43
9.6	10.23	10.13	0.21	0.67	8.99	4.96	5.17	5.54	1.34	5.54
9.8	10.44	10.34	0.21	0.68	9.18	5.07	5.28	5.66	1.37	5.66
10.0	10.658	10.55	0.218	0.698	9.369	5.171	5.389	5.774	1.393	5.774

lifting angle performed by the wheel teeth, which is for an angle of 10° = 6½°.



$b = 0.2887$ (radius of locking circle)

$A = 6° \, 30'$

$a = b. \text{ tang. } A.$

$= 0.2887 . \text{ tang. } 6° \, 30'$

$= 0.2887 . \, 0.1139$

$= 0.03288 .$

Outer diam. $= 1 + 2a$

$= 1 + 2 . 0.03288$

$= 1 + 0.0658.$

$= 1.0658.$

Measured diameter $= 1.0658 . 0.99 = 1.055142.$

COLUMN FOUR.

The thickness of the anchor pins is $= 2\frac{1}{2}°$, measured at the primitive circle of the wheel:

$$\frac{3.1416 . 2.5}{360} = \frac{3.1416}{144.} = 0.02182.$$

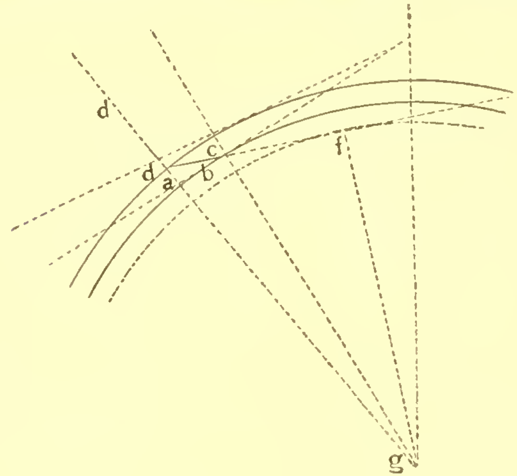
COLUMN FIVE.

The breadth of teeth, measured at the primitive circle, is $= 8°$ of this circle:

$$\frac{3.1416 . 8}{360} = \frac{3.1416}{45} = 0.0698.$$

COLUMN SIX.

The tangent circle for the inclined planes of the wheel teeth. For such a considerable angle (8°) as is given here for the breadth of wheel tooth, the triangle $a \, b \, c$ cannot be supposed to be a rectangular one. The angle at the wheel centre for the tooth being 8°, the two radii enclosing it form with the line b an isosceles triangle, of which the value



of any of the two other angles is $= \frac{180° - 8°}{2} = \frac{172°}{2} = 86°.$

Accordingly, the angle C in the small triangle of tooth $a \, b \, c$ being the supplement to this former, is $= 180° - 86° = 94°$. Thus we know of the triangle $a \, b \, c$:

$a = 0.03288$ (difference of outer and primitive radius of wheel.)

$b = 0.0698$ (breadth of tooth.)

$C = 94°$

$$\text{tang. } B = \frac{b . \sin C}{a - b . \cos . C} = \frac{0.0698 . 0.9976}{0.03288 + 0.0698 . 0.0698}$$

$$= \frac{0.06963}{0.03288 + 0.00487} = \frac{0.06963}{0.03775} = 1.844556.$$

$B = 61° 30'$

In the rectangular triangle $d\,g\,f$, we know:

$dg = 0.53288$ (radius of outer wheel circle)

$B = 61° 30'$

$gf = dg . \sin . B = 0.53288 . 0.8791 = 0.46845$

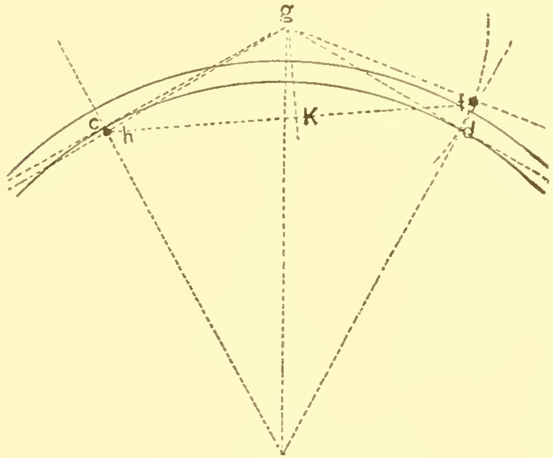
Diameter of tangent circle $2 . gf$

$= 2.0.46845 = 0.9369.$

COLUMN SEVEN.

The distance of the pins—that is, the distance from one centre of pin to the other, is found in the following way:

The triangle $g\,c\,f$ is by the construction an isosceles triangle, the sides $g\,c$ and $g\,f$, and consequently the angles opposite to them, being equal.



The angle $c\,g\,d = 120°$ (by construction)

$< c\,g\,f = < c\,g\,d + < d\,g\,f,$

In the rectangular triangle $d\,g\,f$ there is:

$g\,d = 0{,}2887$ (radius of locking circle)

$d\,f =$ the sum of:

half the thickness of the pin $= 10.0109$

+ the difference of outer and prim. radius $= 0.03288.$

0.04379.

$$\text{tang. } d\,g\,f = \frac{d\,f}{d\,g} = \frac{0.04379}{0.2887} = 0.1517$$

$< d\,g\,f = 8° 40'$

$< c\,g\,f = c\,g\,d + < d\,g\,f = 120° + 8° 40'$

$= 128° 40'$

By the construction, the pin of the entrance arm is supposed to be on the locking, and consequently it will not be in c, but in h, that is, by the locking angle of $1\frac{1}{2}°$ more towords the wheel center. Thus, the angle from the pallet center $h\,g\,f$ in which the two pins stand to each other, is

$= 128° 40' - 1° 30' = 127° 10'$

$$> g\,h\,f = < g\,f\,h = \frac{180° - 127° 10'}{2}$$

$$= \frac{52° 50'}{2} = 26° 25'$$

$$h\,f = \frac{g\,f . \sin h\,g\,f}{\sin g\,h\,f} = \frac{0.2887 . \sin . 127° 10'}{\sin . 26° 25'}$$

$$= \frac{0.2887 . 0.7969}{0.4449} = \frac{0.230065}{0.4449} = 0.5171$$

COLUMN EIGHT.

The distance, measured from the outside of one pin to that of the other, may be useful when it is required to make an escape wheel to a ready made pin anchor. In this case the sizes of columns eight, nine and ten must serve to ascertain the diameter of wheel, proportionate to the anchor.

This distance is the sum of:

the line hf, just calculated $= 0.5171$.
$+$ the thickness of one pin $= 0.0218$.
0.5389

COLUMN NINE.

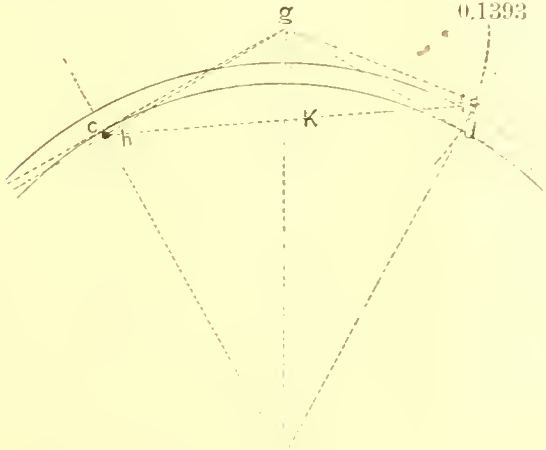
The diameter of the circle from the pallet centre, in which the centres of the pin are embraced, is equal to the diameter of locking circle in Tables II and IV, $= 0.5774$.

COLUMN TEN.

The height of triangle is the distance from the centre of the anchor to the line, touching the two pins on the side turned towards the centre of the wheel.

The line gk, in the diagram belonging to column seven, is $= gf \,.\, \sin.\, gfk = 0.2887 \,.\, \sin.\, 26° \, 25'$
$= 0.2887 \,.\, 0.4449 = 0.1284$.

To this length, half the thickness of the pin must be added $= 0.0109$.
0.1393



When the height of triangle is measured on a ready-made anchor, which will be done in most cases, including the anchor staff, half the thickness of this staff must be subtracted from the measured size.

COLUMN ELEVEN.

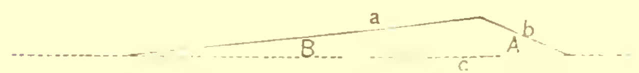
The distance of centres is the same as in all the other tables $= 0.5774$.

Explanation of Table VII.

This table is intended to give the proportions of the acting lengths of lever and impulse pin, and the centre distances for different angles of pallet movement, combined with different angles of lifting at the balance roller.

The calculation of the radius of impulse for a given length of lever is very simple, as these two lengths are in inverse ratio to the angles to be performed by them. For instance, the length of a lever making 10° of movement is to the radius of impulse of a roller which is to make an angle of 40°, as 4 to 1.

The calculation of the centre distance may be illustrated by the following diagram:



a is the length of lever.
b is the radius of impulse circle.
c is the line of centres.
B is half the angle of movement of the pallet, and
A is half the lifting angle on the roller.

$$c = \frac{a \,.\, \sin\,(A+B)}{\sin\, A}.$$

TABLE VII. Proportions of Fork and Roller Action.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Length of lever 1.0.	8° of pallet movement.				10° of pallet movement.						12° of pallet movement.					
	25°		30°		30°		35°		40°		36°		42°		48°	
	Diam. of impulse.	Distance of centres.	Diam. of impulse.	Dist. of centres.	Diam. of impulse.	Dist. of centres.	Diam. of impulse.	Dist. of centres.	Diam. of impulse.	Dist. of centres.	Diam. of impulse.	Dist. of centres.	Diam. of impulse.	Dist. of centres.	Diam. of impulse.	Dist. of centres.
	0.64	1.3124	0.533..	1.2581	0.666..	1.3215	0.5714	1.2727	0.5	1.234	0.666..	1.3097	0.5714	1.2667	0.5	1.2294
3.0	1.92	3.94	1.60	3.77	2.00	3.96	1.71	3.82	1.5	3.70	2.00	3.93	1.71	3.80	1.5	3.69
3.2	2.05	4.20	1.71	4.03	2.13	4.23	1.83	4.07	1.6	3.95	2.13	4.19	1.83	4.05	1.6	3.93
3.4	2.18	4.46	1.81	4.28	2.26	4.49	1.94	4.33	1.7	4.20	2.26	4.45	1.94	4.31	1.7	4.18
3.6	2.30	4.72	1.92	4.53	2.40	4.76	2.06	4.58	1.8	4.44	2.40	4.71	2.06	4.56	1.8	4.43
3.8	2.43	4.99	2.03	4.78	2.53	5.02	2.17	4.84	1.9	4.69	2.53	4.98	2.17	4.81	1.9	4.67
4.0	2.56	5.25	2.13	5.03	2.66	5.29	2.29	5.09	2.0	4.94	2.66	5.24	2.29	5.07	2.0	4.92
4.2	2.69	5.51	2.24	5.28	2.80	5.55	2.40	5.35	2.1	5.18	2.80	5.50	2.40	5.32	2.1	5.16
4.4	2.82	5.77	2.35	5.54	2.93	5.82	2.51	5.60	2.2	5.43	2.93	5.76	2.51	5.57	2.2	5.41
4.6	2.94	6.04	2.45	5.79	3.06	6.08	2.63	5.85	2.3	5.68	3.06	6.02	2.63	5.83	2.3	5.66
4.8	3.07	6.30	2.56	6.04	3.20	6.34	2.74	6.11	2.4	5.92	3.20	6.29	2.74	6.08	2.4	5.90
5.0	3.20	6.56	2.67	6.29	3.33	6.61	2.86	6.36	2.5	6.17	3.33	6.55	2.86	6.33	2.5	6.15
5.2	3.33	6.82	2.77	6.54	3.46	6.87	2.97	6.62	2.6	6.42	3.46	6.81	2.97	6.59	2.6	6.39
5.4	3.46	7.09	2.88	6.79	3.60	7.14	3.09	6.87	2.7	6.66	3.60	7.07	3.09	6.84	2.7	6.64
5.6	3.58	7.35	2.99	7.05	3.73	7.40	3.20	7.13	2.8	6.91	3.73	7.33	3.20	7.09	2.8	6.88
5.8	3.71	7.61	3.09	7.30	3.86	7.66	3.31	7.38	2.9	7.16	3.86	7.60	3.31	7.35	2.9	7.13
6.0	3.84	7.87	3.20	7.55	4.00	7.93	3.43	7.64	3.0	7.40	4.00	7.86	3.43	7.60	3.0	7.38
6.2	3.97	8.14	3.31	7.80	4.13	8.19	3.54	7.89	3.1	7.65	4.13	8.12	3.54	7.85	3.1	7.62
6.4	4.10	8.40	3.41	8.05	4.26	8.46	3.66	8.15	3.2	7.90	4.26	8.38	3.66	8.11	3.2	7.87
6.6	4.22	8.66	3.52	8.30	4.40	8.72	3.77	8.40	3.3	8.14	4.40	8.64	3.77	8.36	3.3	8.11
6.8	4.35	8.92	3.63	8.56	4.53	8.99	3.89	8.65	3.4	8.39	4.53	8.91	3.89	8.61	3.4	8.36
7.0	4.48	9.19	3.73	8.81	4.66	9.25	4.00	8.91	3.5	8.64	4.66	9.17	4.00	8.87	3.5	8.61
7.2	4.61	9.45	3.84	9.06	4.80	9.51	4.11	9.16	3.6	8.88	4.80	9.43	4.11	9.12	3.6	8.85
7.4	4.74	9.71	3.95	9.31	4.93	9.78	4.23	9.42	3.7	9.13	4.93	9.69	4.23	9.37	3.7	9.10
7.6	4.86	9.97	4.05	9.56	5.06	10.04	4.34	9.67	3.8	9.38	5.06	9.95	4.34	9.63	3.8	9.34
7.8	4.99	10.24	4.16	9.81	5.20	10.31	4.46	9.93	3.9	9.63	5.20	10.22	4.46	9.88	3.9	9.59
8.0	5.12	10.499	4.266	10.0648	5.333+	10.572	4.5712	10.1816	4.00	9.872	5.333+	10.4776	4.5712	10.1336	4.00	9.835

Or, supposing a to be $= 1$,

$$c = \frac{\sin (A+B)}{\sin A\,.}$$

Example:

$A = 15°$

$B = 5°$

$$c = \frac{\sin (15+5°}{\sin 15°} = \frac{\sin 20°}{\sin 15°} = \frac{0.342}{0.2588} = 0.1322.$$

The table gives, for greater convenience in practical application, the diameters of the impulse circles instead of the radii, though these latter are, properly speaking, the acting lengths. By this arrangement the practical workman need only make a disc of the exact size of the diameter contained in the table for the special given case, and mark the point for the impulse pin by the edge of this disc.

Calculations to Table VII.

The (acting) length of lever supposed to be = 1.

Column Two.—Angle of pallet = 8°. Angle of roller = 25°. Radius of impulse $= \frac{8}{25} = 0.32$. Diameter of impulse = 2.032 = 0.64.

Column Four.—Angle of pallet 8°. Angle of roller 30°. Radius of impulse $= \frac{8}{30} = 0.266\ldots$ Diameter of impulse = 2.0266... = 0.533...

Column Six.—Angle of pallet = 10°. Angle of roller 30°. Radius of impulse $= \frac{10}{30} = 0.333$. Diameter of impulse = 2.0.333... = 0.666

Column Eight. Angle of pallet = 10°. Angle of roller = 35°. Radius of impulse $= \frac{10}{35} = 0.2857$. Diameter of impulse = 2.02857 = 0.5714.

Column Ten.—Angle of pallet = 10°. Angle of roller = 40°. Radius of impulse $= \frac{10}{40} = 0.25$. Diameter of impulse = 2.025 = 0.500.

Column Twelve.—Angle of pallet 12°. Angle of roller 36°. Radius of impulse $= \frac{12}{36} = 0.333$. Diameter of impulse = 2.0333... = 0.666...

Column Fourteen.—Angle of pallet 12°. Angle of roller 42°. Radius of impulse $= \frac{12}{42} = 0.2857$. Diameter of impulse = 2.02857 = 0.5714.

Column Sixteen.—Angle of pallet = 12°. Angle of roller = 48°. Radius of impulse $= \frac{12}{48} = 0.25$. Diameter of impulse = 2.0.25 = 0.5.

Distances of Centres.

Formula: $c = \frac{a\,.\sin (A+B)}{\sin A\,.}$

$a = 1$.

COLUMN THREE.

$A = 12\frac{1}{2}°$, $B = 4°$ $\quad c = \frac{\sin\,.\,16\frac{1}{2}°}{\sin 12\frac{1}{2}°} = \frac{0.2840}{0.2164} = 1.3124.$

COLUMN FIVE.

$A = 15°$, $B = 4°$ $\quad c = \frac{\sin 19°}{\sin\,.\,15°} = \frac{0.3256}{0.2588} = 1.2581.$

COLUMN SEVEN.

$A = 15°$, $B = 5°$ $\quad c = \frac{\sin 20°}{\sin 15°} = \frac{0.3420}{0.2588} = 1.3215.$

COLUMN NINE.

$A = 17\frac{1}{2}°$, $B = 5°$ $\quad c = \frac{\sin 22\frac{1}{2}°}{\sin 17\frac{1}{2}°} = \frac{0.3827}{0.3007} = 1.2727.$

COLUMN ELEVEN.

$$A = 20^\circ \quad B = 5^\circ \qquad c = \frac{\sin 25^\circ}{\sin.20^\circ} = \frac{0.4226}{0.3420} = 1.234.$$

COLUMN THIRTEEN

$$A = 18^\circ \quad B = 6^\circ \qquad c = \frac{\sin 24^\circ}{\sin.18^\circ} = \frac{0.4067}{0.3090} = 1.3097.$$

COLUMN FIFTEEN.

$$A = 21^\circ \quad B = 6^\circ \qquad c = \frac{\sin 27^\circ}{\sin 21^\circ} = \frac{0.4540}{0.3584} = 1.2667.$$

COLUMN SEVENTEEN.

$$A = 24^\circ \quad B = 6^\circ \qquad c = \frac{\sin.30^\circ}{\sin.24^\circ} = \frac{0.5000}{0.4067} = 1.2294.$$

The following general rules are deductions from the contents of this chapter, and, resuming the constructive necessities for the two actions of the escapement, may be found useful for the replacement of parts in ready-made watches as well as for constructing new escapements.

1. If the diameter of a ratchet wheel, or the primitive diameter of a club or pin anchor wheel is given, the distance of centres is determined, and *vice versa.* (Always supposing a wheel of fifteen teeth and a pallet 'scaping over three teeth).

2. To a given wheel, ratchet or club-toothed, a circular pallet may be made as well as one with equidistant lockings, and the centre distance will be the same in both cases.

3. To a given wheel, the pallet may be made with a large or small angle of lifting; the centre distance will not be altered by this difference.

4. A given pallet will admit but one diameter (primitive diameter) of wheel; any larger or smaller wheel is incorrect. (See Chapter XVI.)

5. To a given pallet the wheel cannot be made at discretion with club or ratchet teeth; for, if the pallet be made for a club wheel, the ratchet wheel would have too much drop, and if it be made for a ratchet wheel, the club wheel would have no drop at all.

6. If the wheel of a pin anchor escapement is given, the lifting of the anchor is determined.

7. If the centre distance of fork and roller and the acting lengths of the two levers of fork and roller are given, both the angles of movement of the fork and roller are determined.

8. If the centre distance, the acting length of the fork, and its angle of movement are given, the acting length of the roller and its angle of movement are determined.

9. If the centre distance, the acting length of fork, and the angle of movement of the roller are given, the acting length of roller and the angle of movement of the lever are determined.

10. If the center distance and both the angles are given, the acting lengths of fork and roller are determined.

11. If the centre distance, the acting length of the roller, and one of the two angles are given, the acting length of the fork and the other angle are determined.

12. If the acting length of the fork and both the angles are given, the acting length of the roller and the centre distance are determined.

13. If the acting length of the roller and both the angles are given, the acting length of the fork and the center distance are determined.

14. If the acting lengths of the fork and roller are given, the respective proportions of the two angles are determined, and *vice versa.*

15. If the acting lengths of the fork and roller and one of the two angles are given, the other angle and the centre distance are determined.

CHAPTER XIII.

PROCEDURE OF MAKING A GOOD AND CORRECT LEVER ESCAPEMENT.

After what has been said in the two last chapters on the proper respective proportions of the acting parts of the lever escapement, it remains but to explain how these proportions may be accurately observed in the process of construction. I deem it unnecessary to explain here the mechanical processes of filing, cutting, polishing, etc., for these are things which can never be learned from books. I treat the subject wholly from a mathematical point of view, firmly convinced that this treatise will be found useful for practical escapement makers, not by teaching them how to file and polish, which they already know as well as any body could teach them, but by explaining to them how to avail themselves of the teachings of science, which exists as well for the watchmaker as for the engineer, and should guide the work of the one as well as that of the other.

For the reader who has thoroughly mastered the contents of the two last chapters the process of making a correct lever escapement, or any part of it, will require little explanation, and as this chapter will probably interest the practical workman more than any other, brevity and simplicity are of the utmost importance.

Except the measuring instruments mentioned in Chapter II, which will be more amply described in Chapter XVI, there are no tools required for sizing the parts and measuring the angles of action, and all the requisites for constructing an escapement of given proportions can be readily made by any workman.

To begin with the ordinary course of making a pallet to a ready-made wheel, we will speak at first of a circular pallet which is to have a total movement of 10°, and to fit to a ratchet escape wheel measuring 6.53 m.

Look in the second column of Table I for the given diameter (the wheel is supposed with cut teeth, and therefore the second column must be used here). From this number proceed in the horizontal range of numbers and note the numbers corresponding to this diameter:

Outer circle of pallet = 4.38 m.
Inner circle of pallet = 3.24 m.
Lifting circle for 10° = 1.64 m.
Height of segment = 3.31 m.

Prepare a slip of good, thin cast steel of suitable breadth and thickness, heat it to a low red heat and leave it on a piece of charcoal, covered with another piece, to cool slowly. Finish the surfaces plane and smooth, and drill a hole in it for the pallet axis. Make the piece blue, for better distinguishing the lines traced upon it.

Make three discs of thin steel plate, whose diameters must be made, by the aid of the micrometer, to correspond exactly to the first three of the above mentioned numbers: 4.38 m., 3.24 m., and 1.64 m. The holes in the centres of of these discs must be exactly the size of the hole drilled for the pallet axis. Then take the largest of these discs and file away as much on one side of it as to make it a segment the size of which when measured from the straight line to the circumference of the circle opposite to it is exactly 3.31 m. as has been found in Table I. Diagram VIII shows these discs.

With a good round pin fitting exactly into both the holes, fit the flattened disc upon the slip of steel prepared to make pallets of, with the flattened side towards the end of the slip, and trace with a very thin and sharp pointed broach the outer circle of the pallet on the slip of steel, quite near to the edge of the disc, and the straight line between the two outermost corners of the pallet. Fix in the same way the second disc and trace the inner circle of pallet round its edge. File away as much of the end of the steel slip as just to touch the straight line traced by the first disc.

The next thing is, to shape the outermost faces of the pallet, which may be done by applying two steel angles, one of 112° to the entrance side, and the other of 124° to the delivery point. Both the sides must be filed away in the direction indicated by these two angles, until they touch the outer corners of the pallet. File out the space between the pallet arms, making the inner faces parallel to the outer planes and the breadth of pallet arms to correspond exactly to the size indicated by Table I, in this case 0.58 m. Fix the third disc, of the diameter 1.64 m., to the pallet, and draw lines from the outer corners of the pallet, to be tangents to this disc. When the ends of the pallet arms are filed away just according to those tangents, the acting parts of the pallet are made, and there remains but to give the pallet a suitable shape.

This is the entire process of making a pallet to a given wheel, and for those especially who make many pallets of the same size, the trouble of making three little steel discs cannot be called a great objection. The two angles required for the outside are the same for all circular pallets of any size whatever.

For making a pallet with equidistant lockings, five steel discs are required, whose sizes must be sought for in Table II. We suppose the measured diameter of the wheel to be 7.72 m., and the angle to be performed, 12°. The corresponding sizes would be:

Outer circle	= 5.86 m.
Locking circle	= 4.50 m.
Inner circle	= 3.14 m.
First lifting circle	= 1.69 m.
Second lifting circle	= 2.91 m.
Height of segment	= 4.23 m.

Five discs must be made of the size indicated by the above mentioned first five numbers, and the largest of them, that of the outer circle, must be flattened away as much as to measure in the right angle to its flattened part, 4.23 m. Then take a slip of steel, prepared as already explained, trace the outlines of the pallet according to the three discs, file the open side of the pallet away until touching the line indicated by the segment, file the locking face of the first pallet arm to an angle of 112° and the outer side of the other pallet arm to an angle of 120°, file out the space between the arms and make their inner faces parallel to the outer ones, giving the arms the breadth indicated by the table to be 0.68 m. Fix the fourth disc on the pallet and trace a tangent to it from the entrance corner of the first arm, fix then the fifth disc and draw a tangent to it from the delivery corner of the second arm. File the driving planes on both the pallet arms to agree with these tangents and then the acting parts of the pallet are of the right size and shape.

In case it is required to make a wheel to a given pallet and centre distance, which occurs often when repairing lever watches, the distance of centres must be measured and the proper size sought in Table I, column 10, if the pallet is a circular one, and in Table II, column 11, if the lockings should be equidistant. Suppose the centre distance to be

5.2 m., we find in the first column of both tables that a disc for a wheel must be turned of a diameter of 9.0 m. This size must be taken in the first column, because there is a full round disc in question here—that is, the wheel before its teeth are cut.

If in any case the given sizes and circumstances should not be found to agree perfectly with the numbers contained in the tables—for instance, if a circular pallet with a movement of 8° is to be made to fit to a wheel of the measured diameter of 6.83 m., the next two diameters in the table must serve to determine the right sizes by a simple system of interpolation. The required size (6.83 m.) is just between the next numbers (in column 2) of which it is the middlerate, and therefore in all the columns wanted the middle of the numbers contained in these two horizontal ranges must be taken:

Outer circle $= \frac{4.52 + 4.65}{2} = \frac{9.17}{2} = 4.58$ m.

Inner circle $= \frac{3.34 + 3.43}{2} = \frac{6.77}{2} = 3.38$ m.

Lifting circle $= \frac{1.44 + 1.48}{2} = \frac{2.92}{2} = 1.46$ m.

Height of segment $= \frac{3.41 + 3.51}{2} = \frac{6.92}{2} = 3.46$ m.

If the diameter of wheel had been 6.78 m., the difference of this size to the next one in the table, 6.73, would be 0.05 m., or one-fourth of the difference between the two next sizes in the table, 6.73 and 6.93. Therefore in all the columns the number in the horizontal range of 6.73 must be taken and augmented by one-fourth of the difference between this and the next number in the same column:

Outer circle $= 4.52 + \frac{0.13}{4} = 4.52 + 0.033 = 4.55$

Inner circle $= 3.34 + \frac{0.09}{4} = 3.34 + 0.02 = 3.36$

Lifting circle $= 1.44 + \frac{0.04}{4} = 1.44 + 0.01 = 1.45$

Height of segment $= 3.41 + \frac{0.10}{4} = 3.41 + 0.03 = 3.44$

The use of Table VII for finding the proportionate lever length and radius of impulse for certain given or intended angles of lifting, is very easy. Supposing the acting length of a lever given to be 4.2 m., having a total movement of 8°, and the lifting angle of the roller intended to be 30°, we must look for the diameter of impulse in the fourth column, where the corresponding size is 2.24 m. Make a disc of steel of that size, fix it on the table roller so that it is concentric with it, and trace the circle in which the acting edges of the ruby pin are embraced, close to the edge of this disc.

If it is required to make a lever and roller to a given centre distance, as 4.45 m., the pallet making an angle of 10° and the lifting angle on the roller intended to be 40°, find in column 11 the number 4.45, and in the same horizontal range the corresponding diameter of impulse will be found in column 10, = 180 m., and the acting length of lever in column 1, = 3.60 m.

If a roller has been lost and is to be replaced so as to give with a lever length of 4.8 m. and a pallet movement of 12°, a lifting angle of 42° on the roller, look in column 1 for the lever length of 4.8 m., and proceed in the horizontal range of that number to column 14, where the diameter of impulse will be found to be 2 74 m.

If in the same case a certain centre distance must be kept, as in most cases of replacing a roller, there is no liberty allowed as to the angle of lifting on the roller. If, for instance, the centre distance is given = 5.9 m., the angle of lifting on the roller must be 18°, and the impulse radius 2.4 m.

When in such case this latter would be made 2.74 m., it would require an alteration of the lever length or centre distance, which cannot be granted in a ready-made watch, and without those alterations it would not perform the intended angle, and would require a wider banking, because it would force the pallet to travel a much greater angle than it requires for escaping.

It might be asked, what is the use of making steel discs for every size, and is it not better to measure directly and trace the circles with a compass or depthing tool? This must be answered in the negative, for no compass or depthing tool can be adjusted so nicely as to distinguish hundredths of a millimeter, but a disc can be directly measured with the micrometer, and consequently be made with all the accuracy required.

CHAPTER XIV.

ON THE MATERIAL EMPLOYED IN MAKING LEVER ESCAPEMENTS.

This is a very important question in the construction of the lever escapement, and every escapement maker should make it the subject of his most earnest study, the more especially as we encounter very diverging opinions among the various manufacturers.

The English lever escapements have almost uniformly a brass escape wheel and the pallet and lever of tempered steel. The Swiss show a greater variety; still, most of their escapement wheels are of tempered steel, and almost all their pallets and a considerable proportion of their levers are of the same material. Sometimes we see levers of brass or German silver, and wheels of brass and gilt; but it seems that in most cases the choice is decided by taste and fancy, without any regard to the practical service of the parts. Supposing the question, which of these materials is the best suited to the acting parts, we will try to elucidate the matter by discussing the reasons for and against each of them.

To begin with steel, it cannot be denied that it is in many essential points a very good material for the parts of escapements. It is tolerably hard and elastic, and susceptible of a beautiful polish. Besides, its specific weight is the lowest of all materials that are applicable. Still, there are very bad qualities in steel, which are greatly to its disadvantage. The first is its liability to oxidize or rust.

When we consider how carefully the escapement maker strives to reduce the friction of the acting parts by giving them the highest polish, it is a discouraging reflection that these beautifully polished surfaces may, by being carelessly touched by a moist hand when the watch is under repair, or even by atmospheric influences, or by the action of gas or vapor of acids, be deprived not only of their nice looking appearance, but also of that smoothness of surface which has been produced with so much care. Many excellent specimens of workmanship are destroyed by this natural defect of the steel.

Another great danger resulting from the employment of steel is its susceptibility of magnetism, especially in watches with compensated balances, which necessarily are made of steel. It has the most detrimental influence on the rate of the watch if, by causes which are not yet fully understood, and which very often cannot be avoided even by the greatest precaution, any part of the escapement has become magnetized. The lever, being the longest part of it, is most of all exposed to magnetic polarity, and the influence is the more pernicious because it is acting on its end. It will there produce quite unaccountable deviations of rate, even in watches in which all the requirements for a good performance are united.

A third and very great drawback in steel as a material, is the necessity of hardening it for such purposes. If not hardened, the steel would hardly offer any essential advantage over other good materials, and the process of hardening involves unavoidable danger to the soundness of the parts. Nobody can guarantee that a hardened piece of the best steel may not have some trifling defect which will render it worthless when ready and finished. True, the skill and care of the workman may reduce the liability of such occurrence, but even then it is bad enough to be aware that there may be hidden some tendency to break in any part of the escapement.

Besides, the necessity of polishing the steel parts all over after having hardened them causes much trouble, especially when the wheel is also made of steel, and necessarily augments the manufacturing expense.

These natural defects would compel the absolute disuse of steel in watchwork if there were another metal known to replace it. So long as this is not the case, we are obliged to make our pinions, arbors, pivots, screws, etc., of steel, but there is no necessity for making the wheel, pallet and lever of our escapements of this material. Therefore we must try to ascertain whether there is any other metal as appropriate, or more so.

Another metal very frequently employed, especially for wheels, is brass. Its qualities render it a very proper material, because when carefully hammered it has considerable density and elasticity. Its specific weight, though about one-seventh more than that of steel, is no objection to its employment, and it is free from the above mentioned natural defects of steel. Therefore we have strong reasons to prefer it to the latter for the material of wheel, pallet and lever. Still, it might be objected that it is impossible to give to the brass, however it might be prepared, the degree of hardness and elasticity which is shown by tempered steel. An escape wheel of brass, as has already been mentioned, should always be polished on its surfaces, and not gilt, for reasons which have been explained in Chapter VIII.

German silver is, in its physical qualities, very much like brass, but experience has shown that the friction in the German silver fork is greater than in forks of brass and steel.

Four or five years ago a new alloy was invented at Vienna, and called sterro-metal. It was said to be of very great malleability, tenacity and elasticity. It occurred to me that it might be very useful for this and similar purposes. I procured a quantity of it, in several different thicknesses, and found its exterior very much like brass, of a rather reddish color. I was told that it was composed of copper, zinc, tin and iron, and its tensile strength was stated by a commission in the imperial arsenal at Vienna to be 4,500 kilogr. on the square-centimeter, and consequently approaching that of cast steel, which is commonly accepted at between 4,900 to 8,300, while that of brass is about half as much. This encouraged me to try the qualities of the sterro-metal for watchmaking purposes. I took five slips of it, each 2.5 m. thick and 18 m. broad, which I worked out in several ways. I took the first between a pair of good flattening rollers and rolled it by degrees down to the thickness of 1.1 m., at which point I was obliged to stop because the metal showed many fissures on its edge. The second specimen was heated red hot and cooled in water. This diminished the hardness a little, but not so much as is the case with brass by heating. Then we worked it out between the rollers to the thickness of 1.1 m., after which I found it quite sound. After once more heating and cooling, we reduced it to 0.6 m. The specimen, though stretched out to more than three times its length, proved to be entirely without defects. I cut a part off, heated and cooled it, and rolled it down to 0.2 m. This was a reduction in thickness to 8 per cent. of its original size, and the soundness of the metal was perfect. The hardness and elasticity were very satisfactory, and it could only be broken by bending it at a very sharp angle. I took then the third specimen, heated and cooled it, and rolled it down to 0.75 m., when it was cracked all over. The fourth specimen I rolled four times with red heat, and then forged the fifth specimen four times, heating it red each time. These two last slips were very good, and of excellent elasticity. These experiments were sufficient to convince me of the advantages to be obtained by the employment of the sterro-metal for lever escapements. I have had many escapements made of it, and never experienced any disadvantage from its use. The high degree of tenacity and ductility shown by it is more than the best English or Bavarian brass could be expected to possess. The specific weight is 8.9, about equal to that of brass, and its expansive ratio is a trifle higher than that of brass.

I also tried the sterro-metal for train wheels, but found it would not answer, because in cutting the teeth it spoils the cutters very soon. The polished surfaces of the sterro-metal do not look so good as those of good, hard brass.

When well hammered, gold is a very good material for lever escapements. It may be said to nearly equal in hardness and ductility the sterro metal, but it breaks more easily. It is not necessary for this purpose to employ gold of 18 carat; the alloy of 12 carat will do quite as well, and is capable of a beautiful polish. Still, its specific weight is an objection against its use. Gold of 12 carat is about 14.0. This is too heavy for parts of an escapement, and increases the inertia considerably, a circumstance not to be underrated in the lever escapement, which has so many intermissions in its action. Besides, the price of the gold would be an objection to its general employment.

Considering its very low specific gravity, aluminium at one time seemed to me a desirable metal for escapements; but it very soon proved quite unfit, because it was found impossible to give it the hardness and elasticity indispensable for this work. One of the alloys of this metal, however, has claimed the attention of mechanicians by its unrivaled strength, and great hardness, and resistance to wear by friction. It is the alloy of copper and aluminium, known under the name of aluminium-bronze. The honor of its invention is a matter of dispute between France and England, the former claiming it for St. Claire Deville and Debray, while the English attribute it to Dr. Percy As the most earnest efforts were at this time universally directed to the complete examination of aluminium and its alloys, it is not unlikely that both invented it independently of one another.

The only aluminium-bronze I have tested in my experiments was that of 10 per cent. aluminium to 90 per cent. of copper. The alloys in which a smaller quantity of aluminium is contained were described in the reports as not promising satisfactory results; besides, the desire for a material of the least specific gravity would naturally lead to the choice of an alloy with the largest proportion of aluminium. But such alloys have been proven brittle, and devoid of the necessary elasticity. The aluminium bronze of 10 per cent. has been found by the experiments of Mr. Anderson, at the Royal Gun Factory, Woolwich, Messrs. Simms, London, and Mr. Morin, Nanterre, to have a tensile strength of 5328 kilogr. on the [] C^m as the mean rate of several trials, thus approaching to the average strength of cast steel. Its resistance to compression and its malleability are very satisfactory, though not of much importance for escapement making. But a very important point, the transverse strength, or resistance to being bent, was found on a comparative trial with brass and gun metal to be:

Brass, - -	2.22
Gun metal, - -	0.15
Aluminium bronze,	0.05

That is to say, three bars of the above mentioned metals, of the same dimensions, were fastened at one end so as to be in a horizontal position, and a certain weight applied to the free end of each bar made that of brass bend 2.22 degrees of the instrument, etc. This experiment proves that the aluminium bronze opposes three times greater resistance to flexion than gun metal, and that its resistance is 44 times as great as that of brass. The expansive ratio is considerably less than that of brass. Its resistance to oxydation by atmospheric influences is not determined, but is certainly greater than that of brass, though inferior to gold of 18 k. Resistance to friction is a quality in which, to judge from the reports, the aluminium bronze is unsurpassed.

This combination of desirable qualities induced me to try the aluminium bronze with special reference to its employment for horological purposes. I took some slips of 10° aluminium bronze plate of 2.5 m thickness, and tried at first how much they could be treated between the rollers without heating. I soon found that this material would not bear a reduction of more than one-fourth to one-third of its thickness without getting many fissures. When heated to red heat and cooled in water, however, after having been rolled down about one-fourth its thickness, it will bear a further operation of the same kind and extent. Thus, by alternate heating and rolling I brought it to a thickness of 0.2 m. The specimen did not show the slightest fissures on its edges, but proved to be of remarkable hardness and elasticity. It occurred to me that it might be useful to make a comparative trial of the resistance to breaking by flexion. I took specimens of sterro-metal, gold and aluminium bronze, each reduced in the most careful way to the thickness of 0.2 m. I found that the specimen of gold when merely bent with the fingers to a right angle, broke short off. The specimen of sterro-metal did not break by this flexion, but in most cases it broke when it was bent into the straight line, or very little beyond it, to the other side. The specimen of aluminium bronze withstood being bent three or four times at right angles alternately to the one and to the other side before it broke, and even then it did not break at once, but only on a part of its breadth, while other parts resisted further flexion. This tenacity is very astonishing, and can hardly be equalled by any other material.

Other experiments in treating the aluminium bronze in a hot state gave very satisfactory results. It opposes a greater resistance to files and cutters than brass or gold do, but the cut of it is very smooth and regular.

cannot be denied that a metal possessing so many valuable qualities is an excellent material for lever escapements. I have made all my escapements of aluminium bronze since that time, and am very well satisfied with it. The polish is beautiful, and it looks very much like gold.

I found this alloy also very useful for other purposes where hardened steel was formerly employed, as for click springs, wheels for keyless winding mechanisms, etc., etc.

I am perfectly aware that I place my opinion in opposition to that of a great majority of horologists, or at least to the usual course adhered to, when I assert that the aluminium bronze is preferable to all materials hitherto in use for wheels, pallets and levers; but with such facts as are contained in the following tables I think it is easy to support my conclusions.

PHYSICAL QUALITIES OF METALS.

The following are the physical qualities of materials mentioned in this chapter, and of some others of possible adaptation to the same purposes, as they could be found in physical treatises, but for the purpose of estimating the relative value of these different alloys as materials for lever escapements, these notations are very unsatisfactory:

	Tensile strength.	Specific gravity.	Expansive ratio.
Gold of 18 k. -	—	about 16.8	0.001466
Gold of 12 k. - -	5000	about 14.2	0.001520
Gold of 9 k. - -	—	about 12.8	—
Silver - - - -	—	10.6	0.001910
German Silver -	5000	8.7	—
Sterro-metal - -	6400	8.4	0.001700
Copper - - -	—	8.9	0.001718
Steel - - - -	8000—9000	7.9	0.001079
Steel hardened -	10000—12000	7.9	0.001240
Brass - - - -	2500	8.7	0.001868
Aluminium - -	—	2.8	—
Aluminium bronze	6400	7.7	0.001600

Finding no more definite information in books, I undertook myself a series of experiments with a view to supplying this deficiency. The qualities necessary in materials for making delicate pieces of mechanism are: transverse strength, resistance against permanent flection, hardness, or resistance against compression, and resistance against breaking by being bent.

The first step in conducting these experiments was to procure bars of all the materials to be tried, of a certain length, and exactly the same profile. To meet the last requirement the employment of round wire seemed the most convenient, because a carefully drawn wire presents in all its length the same thickness, and consequently for finding its profile it was only required to verify the diameter.

I took care to prepare of all the materials wires of exactly the same diameter, and drawn as hard as could be without injury to their soundness. Their diameter was 2.50 m.

For trying the transverse strength, I fixed one end of the wire solidly, and fastened an index upon it at exactly 200 m. from the fixed end. I chose three weights, which were hung on the wire close to the index, and noted the flexion produced by each of them in millimeters. The first of

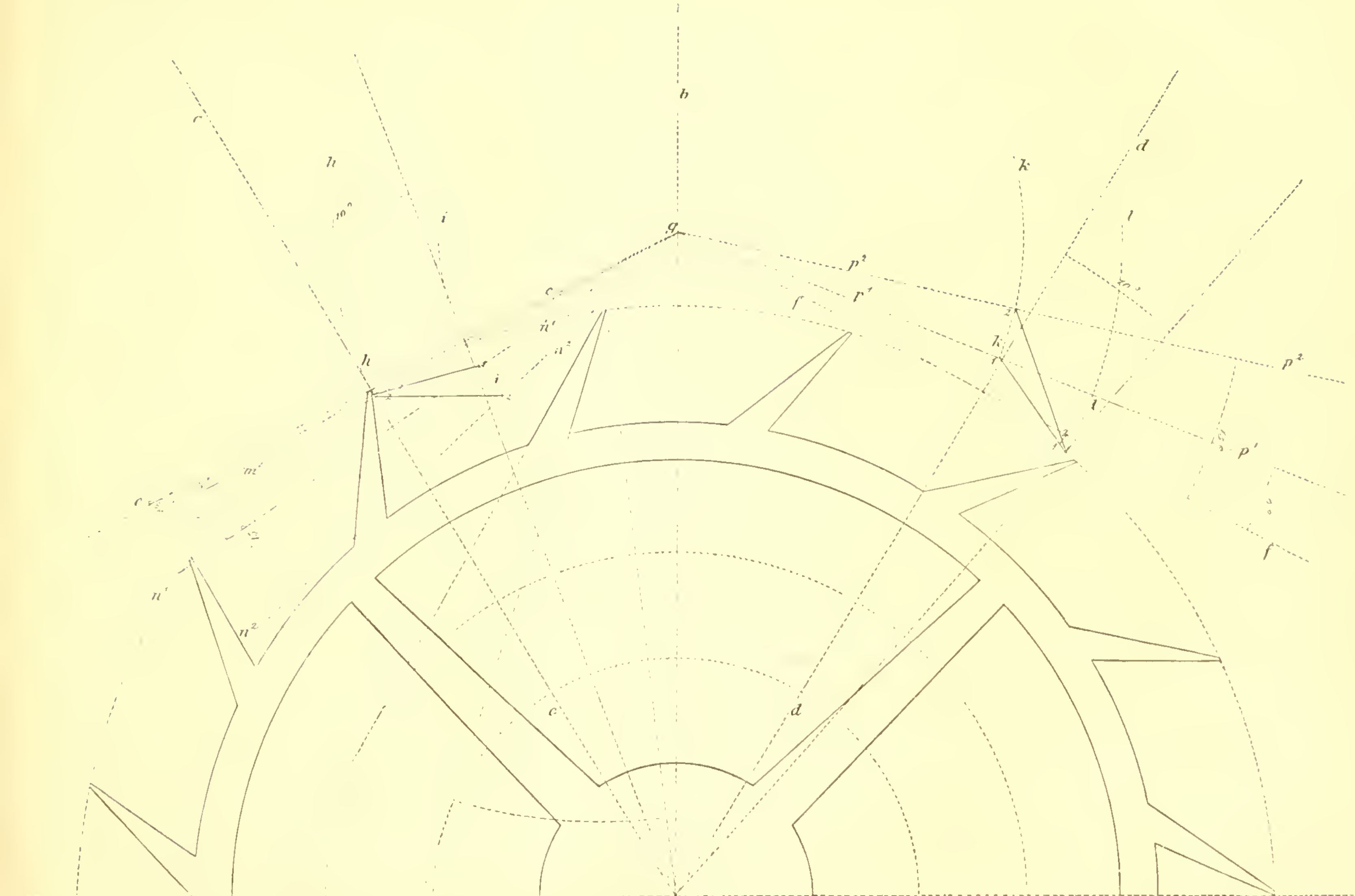


DIAGRAM XVII.

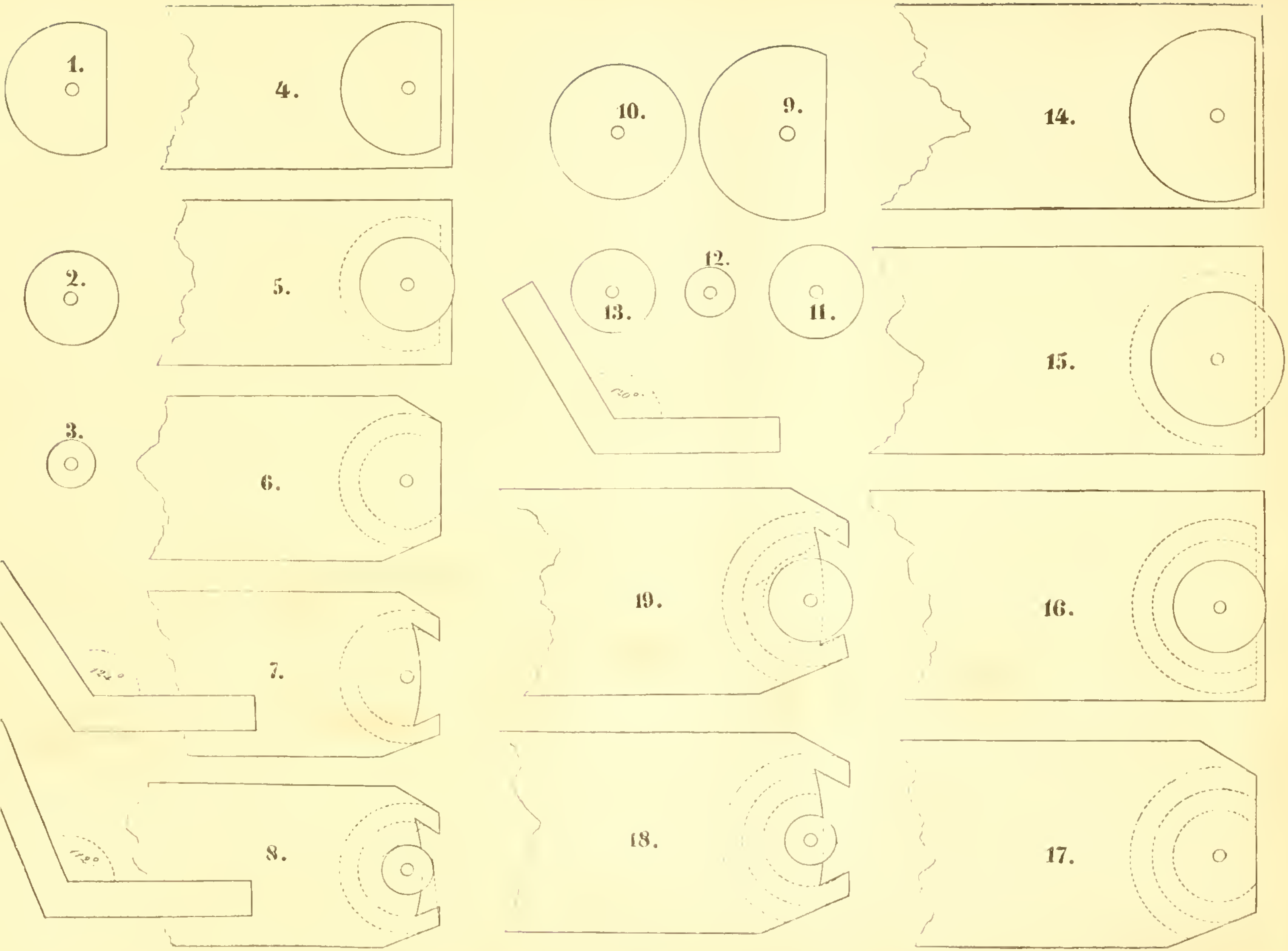


Diagram XVIII.

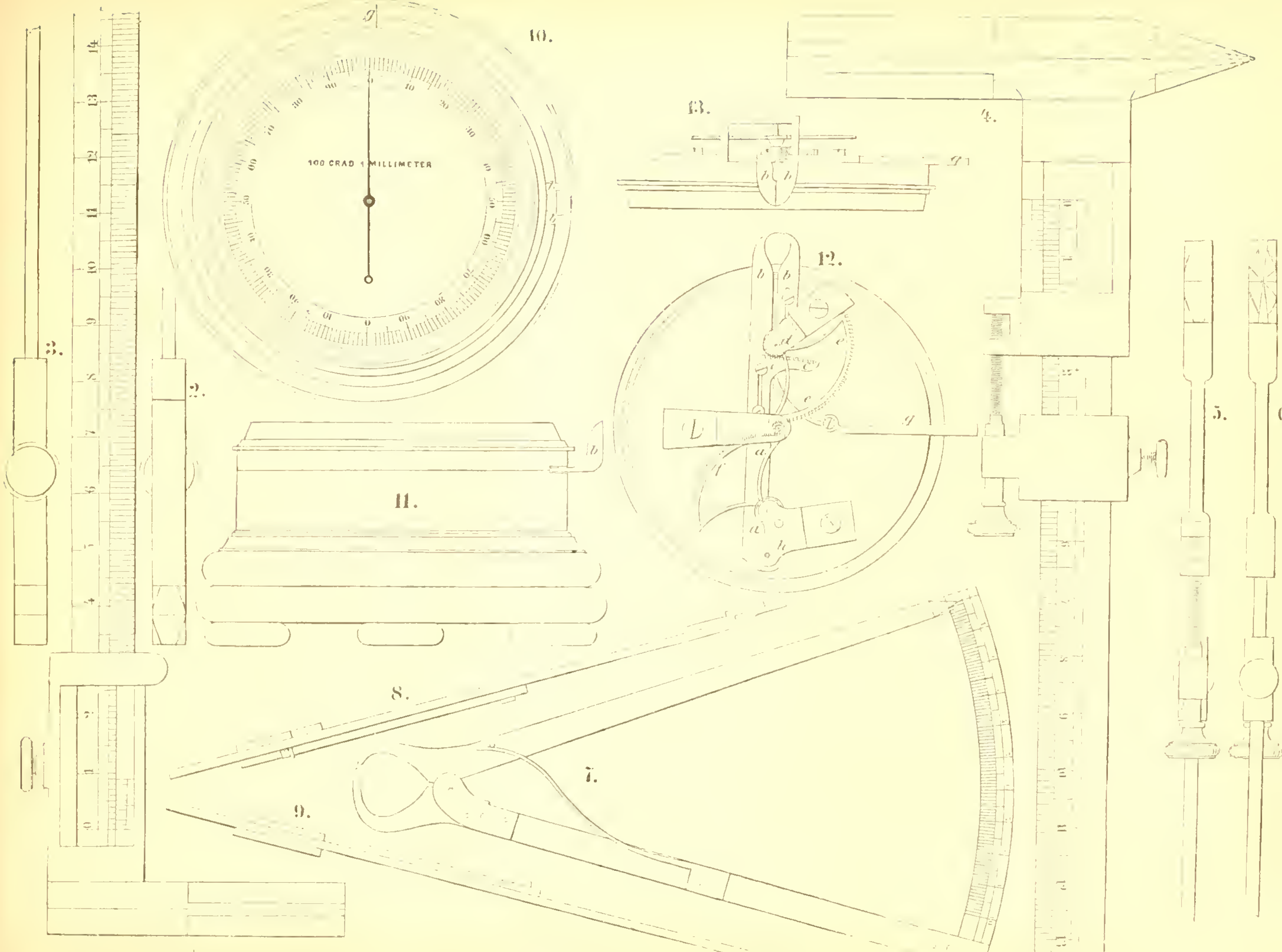


Diagram XIX.

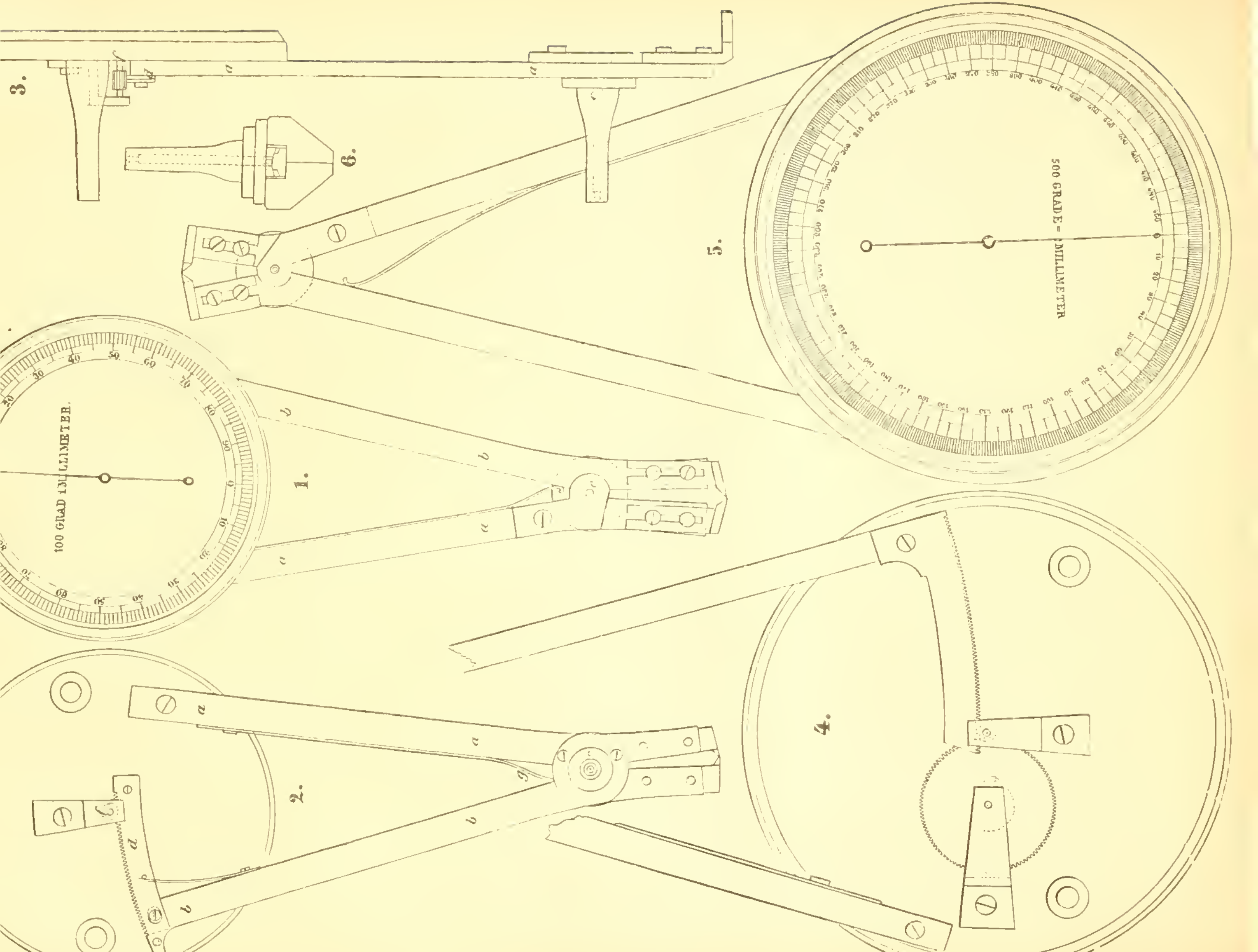


DIAGRAM XX.

these weights was 27 grammes, the second 93.5 gr. and the third 140 gr. They were the same for all the experiments. The flexibility of the different materials was found to be:

	1st weight.	2d weight.	3d weight.
Cast steel (Sheffield) - -	2.1	7.4	11.2
Cast steel hardened, light blue	2.3	8.2	12.4
Cast steel hardened and blue	2.3	8.2	12.4
Cast steel hardened and yellow	2.3	8.2	12.4
Cast steel hardened -	2.4	8.4	12.7
Cast steel hardened and red -	2.4	8.6	12.8
Copper - - - - -	3.7	12.4	18.6
German silver - -	4.0	13.2	19.3
Tombac - - - -	4.0	13.8	20.7
Aluminium bronze - -	4.4	15.2	22.7
Brass from Berlin - -	4.4	15.6	23.4
Gold of 18 k, - - - -	4.7	16.3	24.0
Gold of 9 k. - - - -	4.7	16.4	24.3
Gold of 12 k. - - - -	4.8	16.5	24.4
Brass from Augsburg -	5.2	18.0	27.0
Sterro metal - - -	5.3	18.2	27.1
Silver, standard - -	5.3	18.7	28.1

It will be easily understood that the transverse strength of the specimens must be in the inverse ratio of the numbers contained in this table. But it is not exactly the flexibility or rigidity which must be valued for our purpose; a much greater importance must be attached to the elasticity, or resistance to permanent flexions. At first sight it might appear that a conclusion may be allowed from the transverse strength upon this latter quality, but experiment proved this supposition incorrect. Using rods of the same dimensions as before, I bent each specimen, reading by the aid of a graduated arc and the index on the wire, the extent of flexion; and after leaving the wire free to return to its former position, I verified whether any permanent flexion had taken place. This bending was increased by five millimetres each time, and continued until the permanent flexion amounted to 1 m. or more. The results of these experiments are given in the following table:

	15	20	25	30	35	40	45	50	55	60
Cast steel, hard -	—	—	—	—	—	—	—		brok'n	
Cast steel, hard, yellow	—	—	—	—	—	—	—	—	—	—
Cast steel, hard and red	—	—	—	—	—	—	—	—	—	—
Cast steel, hard and blue	—	—	—	—	—	—	—	—	—	—
Cast steel, hard, light blue	—	—	—	—	—	—	—	—	—	—
Aluminium bronze	—	—	—	—	—	—	—	0.1	0.1	0.2
Sterro metal -	—	—	—	—	—	—	—	—	—	—
Gold of 18 k. - -	—	—	—	—	—	—	0.2	0.2	0.3	0.4
Gold of 9 k. -	—	—	—	—	—	—	—	—	0.1	0.2
Brass from Berlin -	—	—	—	—	0.1	0.1	0.1	0.2	0.3	0.3
German silver -	—	—	—	—	—	—	0.1	0.1	0.2	0.4
Brass from Augsburg	—	—	—	—	0.1	0.1	0.2	0.2	0.5	0.6
Gold of 12 k. -	—	—	—	—	—	0.2	0.3	0.4	0.5	0.7
Silver - - -	—	—	—	—	—	0.1	0.1	0.2	0.4	0.6
Tombac - -	—	—	—	—	—	—	0.1	0.1	0.3	0.7
Cast steel, soft - -	—	—	—	—	—	0.1	0.4	0.5	0.9	1.0
Copper - -	0.1	0.2	0.8	1.0	1.2	0.2				

	65	70	75	80	85	90	100	105	110
Cast steel, hard -	—								
Cast steel, hard and yellow	0.1	0.1	0.1	broken.					
Cast steel, hard and red	—	—	—	—	—	—	—	—	—
Cast steel, hard and blue	—	—	—	—	—	—	—	—	—
Cast steel, hard, light blue	—	—	—	—	—	—	—	—	—
Aluminium bronze -	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.7
Sterro metal - -	0.1	0.1	0.2	0.3	0.4	0.5	0.8		
Gold of 18 k. - -	0.5	0.5	0.6	0.7	0.8				
Gold of 9 k. - -	0.2	0.2	0.3	0.5	0.9				
Brass from Berlin -	0.4	0.6	0.7	1.0					
German silver -	0.5	0.6	0.9						
Brass from Augsburg -	0.8	0.9							
Gold of 12 k. - -	0.9								
Silver - - -	1.0								
Tombac - -	1.7								
Cast steel, soft - -									
Copper - -									

	115	120	125	130	135	140	145
Cast steel, hard -							
Cast steel, hard and yellow							
Cast steel, hard and red -	—	—	—	—	—	0.1	0.1
Cast steel, hard and blue	broken.						
Cast steel, hard and light blue	—	—	—	—	—	—	0.2
Aluminium bronze -	0.8	0.9					
Sterro metal - - -							
Gold of 18 k. - -							
Gold of 9 k. - -							
Brass from Berlin -							
German silver - - -							
Brass from Augsburg -							
Gold of 12 k. - - -							
Silver - - -							
Tombac - - - -							
Cast steel, soft - -							
Copper - - - -							

A comparison between this and the preceding table shows clearly that there is no great connection between tranverse strength and elasticity. For instance, copper is the least elastic of all the materials in the preceding table, but shows sufficient transverse strength to hold first place among the other materials, except steel. Sterro metal shows great flexibility with a remarkable degree of elasticity.

The superiority of aluminium bronze in this respect is also confirmed by my experiments, though I failed to find it so pronounced as Mr. Anderson states it to be. Perhaps he has not tried the metals in the form of round wire, and, which I think most likely, he may have tried them as they were cast, without being hammered or rolled. For watch making purposes, of course, we have to deal with the materials in their greatest density and hardness.

Resistance to compression, or hardness, is another point which I thought desirable to try. Different methods have been employed for this purpose; the manner of testing the hardness of materials in mineralogy, by scraping the one with the other, is the oldest; but for metals this would hardly answer, and would never admit of any exact graduation. Another way was taken by Hugueny. He tried to force a pointed punch into the different specimens by a blow of equal violence, and by the greater or smaller impression made he estimated the hardness of the specimens. This method, though giving much more positive results, did not satisfy me, because the degree of hardness was only to be estimated by vision. I tried to find a way to ascertain by direct measurement the compression resulting from a blow, and to this end employed a little stamping press to produce blows of exactly equal force. In the cylinder of this press I inserted a flat punch of one square centimeter, and the wire specimens served at the same time for these experiments. Thus, by measuring the compression of the part on which the blow had fallen, I obtained the numbers of hardness contained in the following table, and I may remark here that they are the mean rates of three different experiments. It might be said against this method that the employment of wire is not correct, because the impressions cannot be in a regular arithmetic progression with the force of the blow, as might be expected when employing specimens of a rectangular profile. I know that well enough; still, the diameter of the wires and the blow being always exactly the same, I think the results obtained may not be very far from correct.

Finally, I made the resistance to breaking the object of some experiments. I used the same specimens, fastened them in a vise at one end, and bent them to a right angle. After that I bent those which stood against this flexion, straight again to the other side in right angle, and continued so until they broke. By addition of all these angles of flexion which they had *resisted*, I obtained the numbers contained in the second column of the table, which are also the mean rates of three or more experiments, while the third column shows the remarks made upon the manner in which the fracture took place.

	Compression in Millimeters.	Resistance to breaking (in angles).	Remarks about the manner in which it broke.
Cast steel, hard	Burst	5–10°	Very quick.
Cast steel, hard, yellow	Imperceptible	10°	Very quick.
Cast steel, hard and red	0.020 m.	22°	Very quick.
Cast steel, hard and blue	0.027 m.	25°	Very quick.
Cast steel, hard, light blue	0.031 m.	32°	Very quick.
Aluminium bronze	0.367 m.	207°	Quick.
Cast steel, soft	0.398 m.	45–130°*	Very quick.
Gold of 12 k.	0.440 m.	100°	Quick.
German silver	0.488 m.	175°	Middling.
Gold of 18 k.	0.598 m.	110°	Quick.
Gold of 9 k.	0.526 m.	95°	Quick.
Sterro metal	0.549 m.	150°	Very quick.
Brass, Berlin	0.560 m.	303°	Slow.
Brass, Augsburg	0.579 m.	193°	Quick.
Tombac	0.643 m.	210°	Slow.
Silver	0.695 m.	398°	Very slow.
Copper	0.836 m.	170°	Slow.

I am aware these researches were of a rather rudimentary character and might be improved upon in many respects, and for this reason I would have refrained from publishing them but for the entire absence of such tables in general, and especially for horological purposes. In fact, I would feel very much gratified should the incompleteness of the results obtained by me occasion some scientific or practical man to complete or correct them.

One of the most important points, however, could not be tested, which *is the* resistance to wearing by friction, and I fear it would be very difficult to get comparative numbers of any value for this purpose. It would require a great amount of time, many experiments, and some apparatus. Perhaps another may be more fortunate than I in finding a simple way of testing this important quality of materials.

*One and the same foot of steel wire, broken at different places, gave the numbers: 45°, 80°, 95°, 115°, 130°. All the other materials showed a much greater regularity of structure.

CHAPTER XV.

OF THE POINTS TO WHICH THE EXAMINER SHOULD DIRECT HIS ATTENTION.

It is an inseparable consequence of the compound action of the lever escapement that for good performance it is not sufficient only to have its separate actions correct, each in itself, but a perfect harmony between these separate actions is also necessary. Therefore the careful examining of a detached lever escapement is by no means an easy task, for there are many points to be tested on which good performance and time-keeping depend entirely or partly.

To begin with the wheel and pallet action, the examiner must ascertain whether the wheel is perfectly concentric and true in its division, for any want of accuracy in these points diminishes the soundness of action and shortens the mechanical effect, because the amount of drop and locking sufficient for a true and correct wheel would not offer the necessary safety of action.

The cut of the wheel teeth is a matter of some consequence, because the accuracy of division would be prejudiced if the surfaces of the teeth, and especially the acting sides of them, were not cut evenly and smoothly, presenting furrows which might, when coinciding with the point of one tooth and not with that of the other, affect the accuracy of division.

The form of the teeth must be suited to the work to be done, the foreface being sufficiently inclined (undercut) to produce the draw without great friction or adhesion, and the back not more divergent than required for the solidity of the teeth

The examiner must ascertain whether the wheel and pallet are at the proper height to suit each other, and that the end shake of the escape pinion and pallet arbor are equal, or nearly so, to avoid the risk of alteration in the soundness of action arising from the acting of the escape wheel at another part of the driving planes than the highest point of their convexity. To this end it is also essential that the wheel be perfectly true on the flat. The locking and driving planes of the pallet must be examined to see that the surfaces are well polished and the edges carefully rounded, and the drawing inclination in the right proportion so as just to draw the pallet in, without unnecessary unlocking resistance. The pallet and its shape must also have some attention, as it is desirable that it be as light as possible consistent with solidity. Besides, it is necessary that the part between the arms should allow free passage to the wheel teeth without being filed out so much as to endanger breaking near the hole in the center.

The examiner should then try the action of wheel and pallet, to ascertain whether the pallet has been properly pitched. This is very often not the case, and if the pallet be pitched too deep the effect will be an increase of the locking arc, and consequently an addition to the unlocking resistance and to the arc of vibration required for the unlocking Besides, the drop will be unequally divided, too little of it outside and too much inside the pallet, thereby making the action unsafe. This is why a defect of this kind cannot be removed by exchanging the escape wheel for a smaller one, which would only amend the first deficiency without correcting the inequality of drop. If, on the contrary, the pallet be pitched too shallow, the locking will not be safe, and there will be more drop outside and less inside the pallet. Neither would it answer to exchange the wheel for a larger one, for the reasons just mentioned. An alteration of the diameter of the wheel and dressing down that part of the pallet where the drop is not sufficient would restore the necessary extent of the locking arc and make the drop on both sides the same, but as the drop on one side was too much, of course there will afterwards be on both sides an excess of drop, and consequently a loss of power. Therefore, in all cases where the pallet is improperly pitched, the best way will be to alter the pitch in the direction required.

In all cases where the locking is as it should be, but the drop is not equal, the pallet must be considered defective, and should be replaced, as should also a pallet with too much drop.

The examiner must also see that the pallet arms are of equal breadth, because if they are not, there will be unequal distribution of action between the two driving planes, the one lifting more and the other less than it shonld.

With regard to the fork and roller action there are also many essential points to be tested. In first place, the lever must be solidly joined to the pallet in all escapements in which lever and pallet are two separate pieces. Any shake between these parts arising from the pallet arbor or the steady pin not fitting tightly into the holes of either would occasion a great insecurity of action and loss of power. A defect of this kind in a completed watch is not easy to discover, though very easy to remove.

One of the most essential points is, to examine whether the angles of movement produced by the wheel and pallet action and the fork and roller action exactly correspond to each other. It has been shown in a preceding chapter that these angles are quite independent of each other, and that it would be even possible, from a mechanical point of view, to have an extremely large angle at the pallet and a very small one at the roller, and *vice versa.* The lifting at the roller is merely dependent on the respective lengths of the two levers, or the radii, if the angle of pallet motion is given. But when the lever and roller are ready made, the angle of their lifting is in a certain proportion to the angle of pallet movement, and the balance must be pitched exactly so as to produce the angle of lifting for which the proportions of the lever and roller are calculated. If, for instance, the pallet be pitched at a greater distance from the pallet than it should be, a part of the impulse given by the lever is lost in useless drop.

Another inconvenience arising from incorrect pitching is that the ruby pin, in both the unlocking and impelling functions, fails to properly meet the acting faces of the notch in the fork. In such cases the unlocking and impulse would take place at the edge of notch and horn, or at the beginning of the horn, with decided mechanical disadvantage. If, on the contrary, the balance be pitched too close, it will necessitate setting the banking pins farther apart, to allow the ruby pin to perform freely the increased angle of lifting, and by this wider banking the pallet will be drawn farther into the wheel than it should be, thus increasing the unlocking resistance. At the same time, the unlocking function of the ruby pin will be rendered more difficult by its taking place at a greater distance from the line of centers, not to speak of the liability of the ruby pin touching the bottom of the fork, which is not intended for this deeper intersection.

The effects of incorrect pitching of the balance, though very injurious to the performance of the escapement, may easily be removed by an alteration in the length of the two parts; but as the lever is generally finished when the escapement passes examination, we will suppose that it must not be touched, and that the above mentioned defects must be removed by altering the place of the impulse pin.

In the first mentioned case, the impulse pin must be brought a little nearer to the roller edge, to establish a sound intersection and utilize the whole angle of pallet motion. But it must be understood that this alteration, while it restores the correspondence of the lifting angles in the two actions for the given center distance, produces a diminution of the angle of lifting intended for the balance. If, for instance, the 10° of pallet movement were intended to produce a lifting of 40° at the roller, and the lever and roller were made accordingly, but the balance had been pitched at too great distance, the angle of lifting would by the above alteration of the impulse pin be reduced to 36° or 33°; but the angles of the two actions would correspond to each other, and the escapement, though not having the lifting angle formerly intended, would still be correct in itself.

In case the balance is pitched too close, the opposite proceeding will be advisable. The pin must be approached to the center of the roller, by doing which the angle of lifting at the latter is increased. If the circumstances admit, the fork may also be shortened by taking away slightly all along the inner faces of the horn, thereby reducing the acting lever length a little, in order not to alter too much the intended lifting angle. The acting parts of fork and roller must be finished as smoothly as can be, as well as the outer edge of the table roller and the inner side of the horns, and the ruby pin must be fixed upright in the roller; any deviation in whatever direction is defective.

Care must be taken that the pin is tightly fixed in its hole, and that the notch of the fork be of the right size to afford just the necessary freedom of action.

The horns should be examined to see that their length is sufficient to complete the safety action during the period of the guard pin passing the hollow of the roller. This is tested by bringing the balance into the position in which the guard pin begins to enter the passing hollow. In this position the end of the horn should reach at least to the middle of the breadth of the impulse pin. The horns of the forks in escapements with the double roller must be longer than those in the table roller escapement, because the safety action performs a much larger arc of intersection. The eccentricity of the horns may be supposed sufficient if the balance stands with the guard pin just out of the hollow, and the end of the horn is at a very little distance from the impulse pin when the guard pin is pressed lightly against the roller edge.

A defect of very pernicious result to the rate of a lever watch with the double roller in different positions is an excess of length of the impulse pin, when the end of it comes too near the index, and touches it in any position of the watch. This is often caused by a difference of end shake between the balance and pallet staff. These parts and the escape wheel pinion should have nearly the same end shake.

The examiner must also provide carefully for the necessary freedom of the guard pin at the edge of the detaining roller and in the passing hollow. Defects in this particular are very often caused by too much side shake of the balance pivots in their holes, and therefore the holes must also be carefully examined to see that they are not too wide. The guard pin or index must frequently be shortened a little to obtain the necessary freedom of action. If, on the contrary, there is too much space between the guard pin end and the roller edge, so that the wheel tooth is not on the locking when the guard pin is lightly pressed towards the roller edge, and the impulse pin abuts against the end of the horn, the safety action is defective, and must be corrected by the insertion of a larger roller or a longer guard pin.

It must be observed if the notch in the fork be deep enough to let the impulse pin pass freely without getting too near the bottom of the notch.

Care must be taken that the horns of the fork are not too long, so as to rest with their ends against the balance axis.

The pallet and lever must be examined as to their equipoise, and if required, they must be carefully poised. A defect in the equipoise of pallet and lever occasions serious differences of rate in positions, especially in those watches in which the lever is in oblique or right angle to the vertical line from the pendant through the middle of the watch.

Finally, the banking must be looked into. This should not be wider than just to allow sufficient freedom for the movement of the acting parts. It is also very essential that the banking pins be straight and vertical to the plate, for if they are not, and the pallet staff has a little too much end shake, the width of the banking will be considerably altered, whether the watch is lying on the back or on the glass, especially when the banking pins are not standing near the fork end of the lever.

Lever watches in which no faults can be found in the escapement in the above mentioned points offer good promise of satisfactory performance.

CHAPTER XVI.

ON THE SYSTEM OF MEASUREMENT AND THE MEASURING INSTRUMENTS.

It has already been mentioned, in Chapter II, that one of the greatest difficulties for the practical horologist is, that he is constantly under the necessity of executing the details of his work on a very small scale. This difficulty is much increased by the fact that the nature of the work and the purpose of the parts constructed demand the utmost precision in sizes and proportions. This technical impediment is generally acknowledged, and has perhaps in no small degree contributed to raise the horological profession to the particular esteem it enjoys in the eyes of the public. But the difficulty of his occupation alone, in itself, does not entitle the horologist to this esteem; for no man will be estimated simply for having undertaken a difficult task. The great point consists in the skill and energy he employs in overcoming the difficulties he encounters. If we apply this truth to the before-mentioned practical difficulty of horological construction, we shall be compelled to put the question to ourselves: "*What have we done to overcome in a successful manner the difficulties arising from the very small dimensions of our work?*"

The answer to this question, if we are honest and candid, is hardly gratifying to the community of watchmakers as a body, because it must be admitted that nothing has heretofore been done to prepare a safe and rational footing for every one in the trade. The surmounting of the difficulty has been left to the personal efforts of individual workmen, and they have done as well as they could. It cannot be denied that the skill and sagacity with which many practical men have succeeded in the solution of the problems in their peculiar branch are extremely creditable and praiseworthy. But such successful endeavors, creditable as they may be to the genius of those practical men, are by no means an argument for the sufficiency of the system of working actually in use; on the contrary, they must be looked upon as proof of what a considerable amount of ingenuity and patience must have been required to obtain satisfactory results with such very insufficient means.

The next consequence of this answer to the first question must be the second question: *What must be done in order to introduce a better state of things?*

There is but one answer to this question: *Introduce a universal measuring standard* into English watch and clock manufacturing, *fit for intercomparison*, which is the first condition of mutual understanding on questions of size. The complete want of such a standard will never be satisfied by the multitude of arbitrary gauges and calipers produced by the immediate want of individuals, and applying only to special purposes. It is certainly one of the most important and creditable steps of the British Horological Institute to have interposed its influence in this matter, and raised its appeal for the promotion of this aim. When the question is to decide *which standard is to be chosen* for universal introduction in the watch and clock manufacture, there are many essential points to be taken into consideration:

1. *The system to be introduced must be applicable to calculation.* Calculation is the basis upon which every mechanician should work, and for the watchmaker its necessity is of a double nature. It has before been observed that two courses may be taken. The one is the way of calculating the proportions, as indicated in Chapter XII; but as there are not many practical men able or willing to undertake those calculating operations, the graphic system, consisting in drawing the objects to be constructed on a large scale, and in strict accordance with the proportions dictated by mechanical rules, may be considered as an admissible expedient. This method of proceeding, however, requires the subsequent reduction of the sizes in the drawing to the working size, which is made by such simple calculations as are familiar to a man of but little education or attainments. Therefore, even the employment of the graphic method does not exclude calculation. *Any system of measurement will be unfit for calculation, unless its division is strictly decimal.*

2. *The unit of a standard for watchwork should be of a dimension corresponding to the dimensions of watchwork.* The inch, for example, even if divided decimally, is not an appropriate unit for our purpose, because it is much too large. Watchwork is not a kind of work to be measured by inches. The difference between the largest and smallest sizes of movements does not amount to an inch. Now, when such extreme differences can only be expressed by fractions of the unit, we must conclude that this unit is too large. This deficiency of the inch system has been much felt in the trade, and this impression manifests itself by a sizing of the movements and other objects, which has no connection with the inch, and is expressed in merely conventional numbers. When speaking of a movement of 14-size, nobody can form by this number the slightest conception of the diameter meant by it, and it may be considered rather doubtful whether watchmakers agree perfectly between themselves as to the exact dimensions represented by those

sizes. The Swiss manufacturers have taken a more positive step by indicating the sizes of their movements by French lines, which are nearly equal to the intervals of the English sizes. Every man, whether he be a watchmaker or not, is enabled to verify the diameter of a watch movement which is said to be one of 19 lignes.

After it has been proven by the above example that the inch is too large a unit to measure movements with, it must be much more improper for the very small interior parts of the watch. The inch is sufficiently small for mill work and steam engines, but it will never answer as a unit for watchwork sizes.

3. *The system chosen should offer the prospect of as universal adoption as possible.*

It will require no proof that in our time, when distances are reduced by steam and electricity and bars to international communication are removed by treaties, when the loyal and liberal interchange of ideas and experiences between cultivated nations become stronger every day, that amidst these anxious exertions of the civilized world to promote association it would ill become a body of scientific Englishmen to create a standard in the use of which they would only have the Russians to keep them company, and even those probably but for a short time. This would indeed be erecting a kind of a Chinese wall around English watch and clock manufacture.

4. *The system to be introduced must not only be perfect in theory, but it should be accompanied by the means of turning it into profit for any purpose in practical work.* These means are the measuring instruments.

5. *The measuring instruments must be of such a nature as not to depend upon the sight,* which will not answer when great accuracy is required, The object to be measured must be seized between two parts of the instrument, and the index must register the size.

It would, for example, be impossible to verify the outer diameter of a pinion to the one-hundredth of an inch with an instrument recommended not long ago in the *Horological Journal,* under the head: "The Inch Decimally Divided." It is a small rule, on the edges of which a length of two inches is divided into 50 and 100 parts. Besides, a difference of one-hundredth of an English inch is a very essential amount for watchwork. Let us, then, examine from these points of view whether the metrical system, which is the basis of all the tables and calculations in this treatise, would be suitable for the purpose.

1. Its applicability for calculation cannot be doubted, because its division is purely decimal, and, by being so, superior to any other system. It would be a very tiresome task to prepare or to use tables of proportions founded upon a system of measurement not decimally divided.

2. Its proportions to the dimensions of watchwork requires no demonstration. The millimeter is about one twenty-fifth of the English inch and about two-fifths of the French line, thus admitting of operation with integer numbers, while with a larger unit the same sizes must be expressed by fractions.

3. Regarding the prospect of its spreading over the civilized world, the metric system stands decidedly the best chance, and the arguments which have been adduced in behalf of the English inch from this point of view are, on close investigation, of very little value. It has been said by Mr. Rankine that as the English inch is used in Great Britain, Russia and the United States, it is consequently used by one-fourth the population of our planet, which could not be said of any other standard measure. I think there never was a more unfair statement than that. Mr. Rankine cal-

culates the population of Great Britain at 174,000,000, of course including India, Australia, etc. At least three-fourths of this number of British subjects are quite ignorant of the fact that there is such a thing as the English inch existing in the world. The population of the Russian empire, too, stated to be 64,000,000, must contain all the different tribes of Eastern Europe and Asia, the Bashkirs, Tartars, Calmucks, Kirgheese, etc., who according to all probability measure merely by the spanning of their fingers or by the length of their own feet, instead of by the English foot and inch. Very likely the estimate of population in the United States at 32,000,000 is also swollen to that amount by including the backwoodsman and the red skin, as well as the negroes. A reduction of the alleged total number of 270,000,000 to one-fourth of that amount will certainly not be unfair when the question is to be decided how many people are measuring by English inches. When we compare this reduced number with the population of France, consisting of about 40,000,000 of civilized people, to whom the measuring standard is a familiar thing, augmented by the Spanish and Italian nations, who very soon, we hope, will be joined by the German nation in its totality, not to speak of Belgium and other small states, it may be assumed that the adherents of the English standard are considerably outnumbered.

4. The requirement of the new system being accompanied by the necessary instruments for practically using it may be answered in favor of the metrical system by the following description of the measuring instruments as they have been used in the watch manufactories of Glashutte for more than twenty years by a considerable number of workmen and employers.

5. It will be seen by the subsequent description of the measuring instruments that they are so constructed that the measuring is not intrusted to the touch or sight, but that on the contrary it is effected by mechanical means, and the result brought to view by an index.

The metric measuring system has been introduced in Glashutte since the commencement of watch manufacturing, in 1845, by the founder, Mr, A. Lange, who even at this early period adopted this system in consideration of its general superiority and special applicability to watch work. The construction of the round micrometer is due to Mr. Lange.

DESCRIPTION OF THE MEASURING INSTRUMENTS USED AND MANUFACTURED IN GLASHUTTE.

1. The meter measure is a kind of sliding rule with rectangular arms, between which the objects to be measured are inserted. The edge of the rule is divided by millimeters, and with the aid of a vernier the tenths of millimeters can be read.

This instrument is very convenient for use as a rule and angle, and to verify the parallelism of two planes by applying the measuring arms. The diameters of wheels, barrels, plates, glasses, etc., may be measured with it in the readiest and most accurate manner to one-tenth of the millimeter. (See Diagram XIX, Figs. 1, 2 and 3.)

For the purpose of drawing or tracing calculated lengths upon metal it is very convenient to have two points on it, and the accurate adjustment is facilitated by an adjusting-screw. (Figs. 4, 5 and 6, same Diagram.)

2. The tenth measure is illustrated by Figs. 7, 8 and 9, and its construction being very simple, it will not require explanation. It will be found very useful for measuring the bottoms of barrels or sinks, for measuring objects on the lathe, for testing the thickness of wire and plate, etc. The

index shows the measured size in tenths of a millimeter. A total opening of 10 m. is provided, and therefore the arc is divided into 100 parts.

3. The micrometer is illustrated by Diagram XIX, Figs. 10, 11, 12 and 13. It shows a pair of small steel tongs, *b b*, one-half of which is fixed solidly upon the plate, while the other half is fastened to the end of lever *a*, movable on two pivots around the point *h*. For multiplying the movement of this lever, in order to make it more perceptible to the eye, the lever *a* carries a rack *c*, fixed on it concentric to the point *h*. This rack gears into a pinion *d*, on the arbor of which is mounted the small rack *e*; this latter drives the center pinion, which carries the hand on its projecting pivot. These two elements give a total multiplication of 180. The dial is divided into 200 parts, so that half a revolution of the hand indicates the size of 1 millimeter. But there would be no reliability on the registrations of the hand on the dial if the shake which the centre pinion must necessarily have for free action were not removed, because the hand would shake more than one degree, and thus destroy all accuracy of measuring. Therefore, the second small rack *f*, pitching also into the center pinion, has a pendulum spring mounted upon it, with a tendency to move the center pinion back. An angular lever, *g*, projecting at the outside of the case, serves to open the tongs. The object to be measured must be inserted between the opened tongs, and when the lever *g* is let loose the tongs will hold it, if it is not too heavy, by the tension of the pendulum spring constantly acting in a direction so as to shut the tongs The hand on the dial shows the distance at which the two parts of the tongs are kept apart by the object between them, or, which is the same, the thickness of this object. The total opening of the instrument is 6 to 8 m. The hundredths of a millimeter indicated by this micrometer are commonly called degress by our workmen, and this degree is the unit for pivots and other small objects.

A measurement by hundredths of millimeters is a very minute one, for the thinnest measurable object, the human hair, for instance, measures 4 to 6 degrees. The thinnest paper shows a thickness of 3 degrees.

This instrument, as well as the tenth measure, has a mathematical defect, because it measures the arc described by the tongs, and not the chord of this arc, which latter is the true thickness of the measured objects. This error increases with the angle of opening. Of course it will be of much more consequence in the tenth measure, but in this instrument the error is compensated as much as possible by dividing a straight line into 100 parts, and transferring this division to the arc of the instrument. For the micrometer this elimination of the error is impossible, but happily it is not of so great consequence, because its angle of opening, *a c* supposed to be = 6 m., amounts only to 6°. The error arising out of the difference between the arc and chord of an angle of not more than 6°, is very trifling, and may be ignored altogether, even where great accuracy is required.

The micrometer is commonly made with a base of wood, to have it at convenient height from the surface of the table. The nicety of measuring with the micrometer may be tested by an experiment: Take a piece of brass wire about 1 m. thick, put one of its ends between the tongs of the micrometer, support the other end, put a lamp under the wire at about 1 to 1½ inches distant from the tongs, and heat the wire to a low red heat. The expansion of the wire will be indicated by an evident movement of the hand, and the subsequent contraction through the cooling of the wire will cause the reverse of this movement.

These three instruments, the meter measure, the tenth measure and the micrometer, are quite sufficient for all practical wants of watch and clock making. Their application for the graphic method of working is the following: Suppose that a circular pallet is to be made to a ratchet wheel, the real diameter of which is = 8 m.

The diameter of the wheel, as drawn in Diagram 2, is 200 m., or 25 times the size of the wheel to which the pallet is to be made. Therefore all the sizes of the pallet in the drawing must be measured with the meter measure and divided by 25 or multiplied by 0.04, to give the working sizes. The inner circle of pallet, for example, has on the drawing a diameter of 98 m. The disc of this circle (Chapter XIII) must therefore be made $\frac{98}{25} = 3.92$ m. or 392 degrees of the micrometer, etc. This is also the size indicated by Table I for the diameter of inner pallet circle when the real diameter of the wheel is = 8 m.

It is frequently the case that micrometers are ordered for special purposes, such as for iron works, to verify the thickness of wires, for pianoforte makers for the same purpose, for paper mills to guage the quantity of material required for a certain sheet of paper, for spinning establishments to ascertain the thickness of the yarns, etc. I have often found that micrometers employed for these technical purposes do not always meet with the careful treatment watchmakers are accustomed to accord their tools, and sometimes I receive the instruments back for repair in very bad condition. This prompted me to devise a measuring instrument which would stand rough treatment without getting out of order, yet possessing the same accuracy as the micrometer. It occurred to me that the multiplication effected in the micrometer by two depths might be attained with one depth only by employing longer levers. Diagram XX, Figs. 1, 2 and 3, show the simplified micrometer. One of the two arms, *a a*, is fastened to the plate and carries the foot *c*, serving as the center of motion, and on its other extremity the fixed half of the tongs. The other arm, *b b*, turns round its axis in *c*. The foot is hollowed out to receive the arbor, and the lower pivot moves in a hole near the lower end of the foot, while the upper pivot is fitted into a cock screwed upon the upper surface of the fixed arm, *a a*. This arrangement allows a greater length of the axis, and consequently a greater soundness of movement. The movable arm *b b* carries on the extremity of its long lever a rack, *d*, concentric to the point *c*, and pitching into a pinion, *f*, of fifteen leaves in the center, the projecting pivot of which carries the hand. The shake of the pinion and hand is eliminated by a secondary rack, identical to the other, and fixed upon it with two screws, leaving it a small shake in the direction in which the rack is moving. A small spring is constantly pressing against the secondary rack, so that its teeth always stand a trifle beside those of the fixed rack, thus exerting an elastic pressure on the pinion leaves, and removing the shake without prejudice to the freedom of movement. The extremity of the short lever of the movable arm *b b* carries the other half of the tongs, corresponding to that on the arm *a a*. A long flat spring, *g*, with a tendency to shut the tongs, completes the arrangement.

This simplified micrometer has given very satisfactory results. The dial and its division is entirely the same. Its parts are strong enough, and so very simple that it does not require the care of a watchmaker to keep it in acting order. The greater simplicity of construction admits also its selling at a cheaper price than the round micrometer.

There may be some objection to a micrometer of this kind, in that the unavoidable error formerly alluded to arising from the difference between arc and chord is much more marked, because the shortness of the lever arms carrying the tongs requires a larger angle of opening. In fact, this angle is = 15° for an opening of 6 m. Nevertheless, this instrument will be found to answer very well, as many comparative experiments have convinced me that in point of accurate measuring they are in no way inferior to the round micrometer. I attribute this favorable result to the omission of one depth, for pinions and wheels, if even made with the greatest care, will always bear some trifling unequalities which, by a multiplication of more than 100, become considerable quantities.

After having tested this principle I received orders for instruments for special purposes, one from a manufacturer of gold and silver lace, for measuring the finest threads, and the other for a scientific amateur, both requiring a direct measurement of 1-500 m. I did not think it advisable to entrust a measurement of such subtlety to the enormous multiplication by two depths, but constructed the instrument in the same way as the preceding. The arms are longer and the dial is larger, and divided into 500 degrees. One revolution of the hand is = 1 m. (Diagram XX, Figs. 4, 5 and 6.) Since that time I have manufactured many such instruments for special purposes, and, as far as I know, they give satisfaction.

This measuring system may prove very useful for the English watch and clock manufacture if universally introduced.

Finally, I thought it would be convenient to the readers of this treatise to have joined to it tables of reduction, in order to compare easily the sizes in millimeters with those expressed in English inches and French lines.

Table X.

Millimeter.	English inch.	French line.
0.01	0.0003937	0.004433
0.02	0.0007874	0.008866
0.03	0.0011811	0.013299
0.04	0.0015748	0.017732
0.05	0.0019685	0.022165
0.06	0.0023622	0.026598
0.07	0.0026559	0.031031
0.08	0.0031496	0.035464
0.09	0.0035433	0.039897
0.1	0.003937	0.04433
0.2	0.007874	0.08866
0.3	0.011811	0.13299
0.4	0.015748	0.17732
0.5	0.019685	0.22165
0.6	0.023622	0.26598
0.7	0.026559	0.31031
0.8	0.031496	0.35464
0.9	0.035433	0.39897
1	0.03937	0.4433
2	0.07874	0.8866
3	0.11811	1.3299
4	0.15748	1.7732
5	0.19685	2.2165
6	0.23622	2.6598
7	0.26559	3.1031
8	0.31496	3.5464
9	0.35433	3.9897
10	0.39370	4.4330
11	0.43307	4.8763
12	0.47244	5.3196
13	0.51181	5.7629
14	0.55118	6.2062
15	0.59055	6.6495
16	0.62992	7.0928
17	0.66929	7.5361

Millimeter.	English inch.	French line.
18	0.70866	7.9794
19	0.74803	8.4227
20	0.78740	8.8660
21	0.82677	9.3093
22	0.86614	9.7526
23	0.90551	10.1959
24	0.94488	10.6392
25	0.98425	11.0825
26	1.02362	11.5258
27	1.06299	11.9691
28	1.10236	12.4124
29	1.14173	12.8557
30	1.18110	13.2990
31	1.22047	13.7423
32	1.25984	14.1856
33	1.29921	14.6289
34	1.33858	15.0722
35	1.37795	15.5155
36	1.41732	15.9588
37	1.45669	16.4021
38	1.49606	16.8454
39	1.53543	17.2887
40	1.57480	17.7320
41	1.61417	18.1753
42	1.65354	18.6186
43	1.69291	19.0619
44	1.73228	19.5052
45	1.77165	19.9485
46	1.81102	20.3918
47	1.85039	20.8351
48	1.88976	21.2784
49	1.92913	21.7217
50	1.96850	22.1650

Table XI.

English inch.	Millimeter.	French line.	English inch.	Millimeter.	French line.
0.001	0.025399	0.011260	0.1	2.5399	1.12595
0.002	0.050798	0.022519	0.2	5.0798	2.25190
0.003	0.076197	0.033779	0.3	7.6197	3.37785
0.004	0.101596	0.045038	0.4	10.1596	4.50380
0.005	0.126995	0.056298	0.5	12.6995	5.62975
0.006	0.152394	0.067557	0.6	15.2394	6.75570
0.007	0.177793	0.078817	0.7	17.7793	7.88165
0.008	0.203192	0.090076	0.8	20.3192	9.00760
0,009	0.228591	0.101336	0.9	22.8591	10.13355
0.01	0.25399	0.112595	1.0	25.3990	11.25945
0.02	0.50798	0.225190	1.1	27.9389	12.38545
0.03	0.76197	0.337785	1.2	30.4788	13.51140
0.04	1.01596	0.450380	1.3	33.0187	14.63735
0.05	1.26995	0.562975	1.4	35.5586	15.76330
0.06	1.52394	0.675570	1.5	38.0985	16.88925
0.07	1.77793	0.788165	1.6	40.6384	18.01510
0.08	2.03192	0.900760	1.7	43.1783	19.14105
0.09	2.28591	1.013355	1.8	45.7182	20.26700
			1.9	48.2581	21.29295
			2.0	50.7980	22.51890

Table XII.

French line.	English inch.	Millimeter.	French line.	English inch.	Millimeter.
0.01	0.000888	0.0225583	0.1	0.008881	0.225583
0.02	0.001776	0.0451166	0.2	0.017763	0.451166
0.03	0.002664	0.0676749	0.3	0.026644	0.676749
0.04	0.003552	0.0902332	0.4	0.035526	0.902332
0.05	0.004440	0.1127915	0.5	0.044407	1.127915
0.06	0.005328	0.1353498	0.6	0.053288	1.353498
0.07	0.006217	0.1579081	0.7	0.062169	1.579081
0.08	0.007105	0.1804664	0.8	0.071051	1.804664
0.09	0.007993	0.2030247	0.9	0.079933	2.030247
1.0	0.088814	2.25583	11.0	0.97696	24.81413
2.0	0.177628	4.51166	12.0	1.06577	27.06996
3.0	0.266442	6.76749	13.0	1.15458	29.32579
4.0	0.355256	9.02332	14.0	1.24340	31.58162
5.0	0.444070	11.27915	15.0	1.33221	33.83745
6.0	0.532884	13.53498	16.0	1.42103	36.09328
7.0	0.621698	15.79081	17.0	1.50984	38.34911
8.0	0.710512	18.04664	18.0	1.59865	40.60494
9.0	0.799326	20.30247	19.0	1.68747	42.86077
10.0	0.88814	22.55830	20.0	1.77628	45.11660

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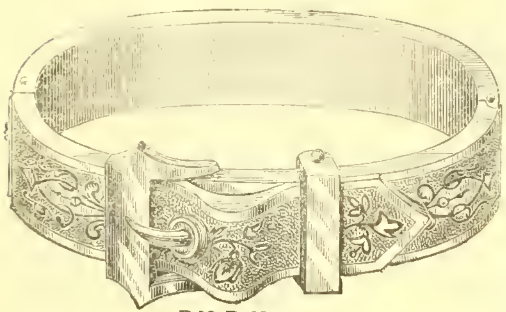

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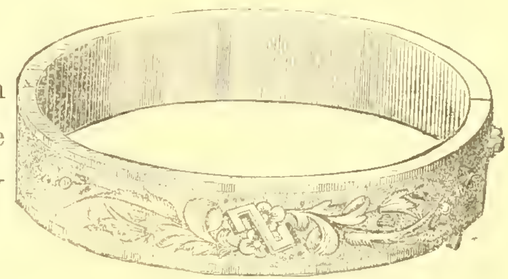

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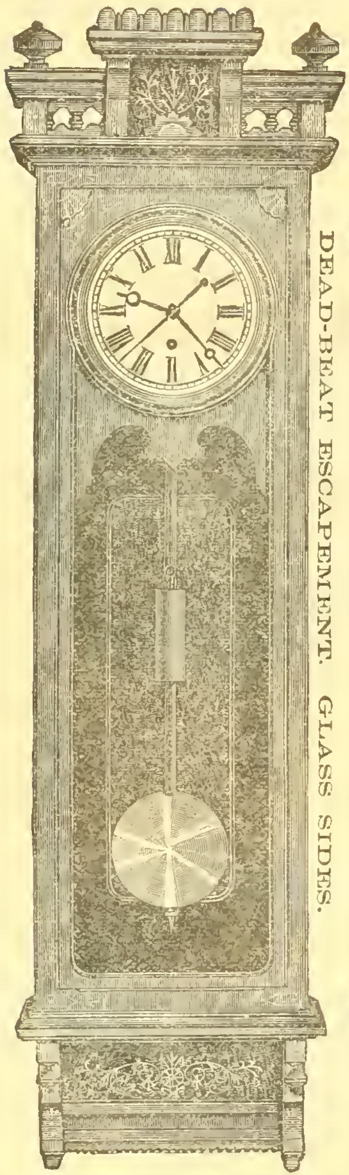

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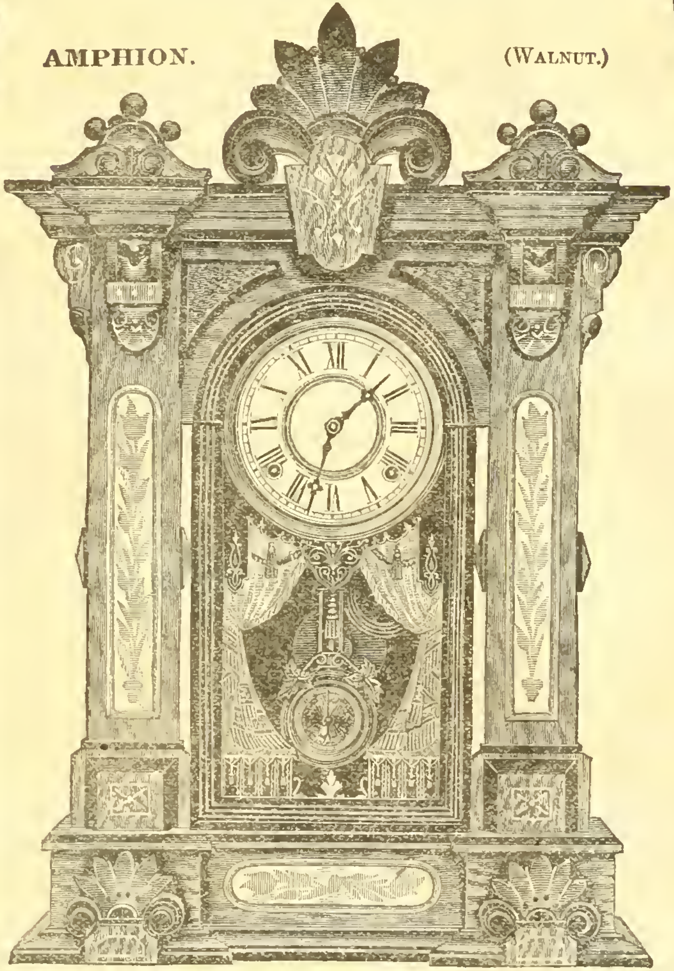

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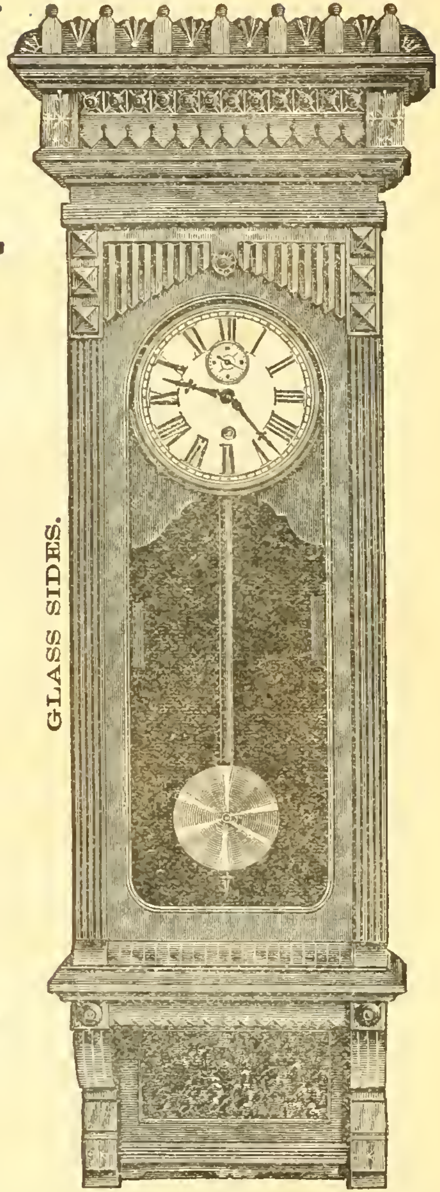

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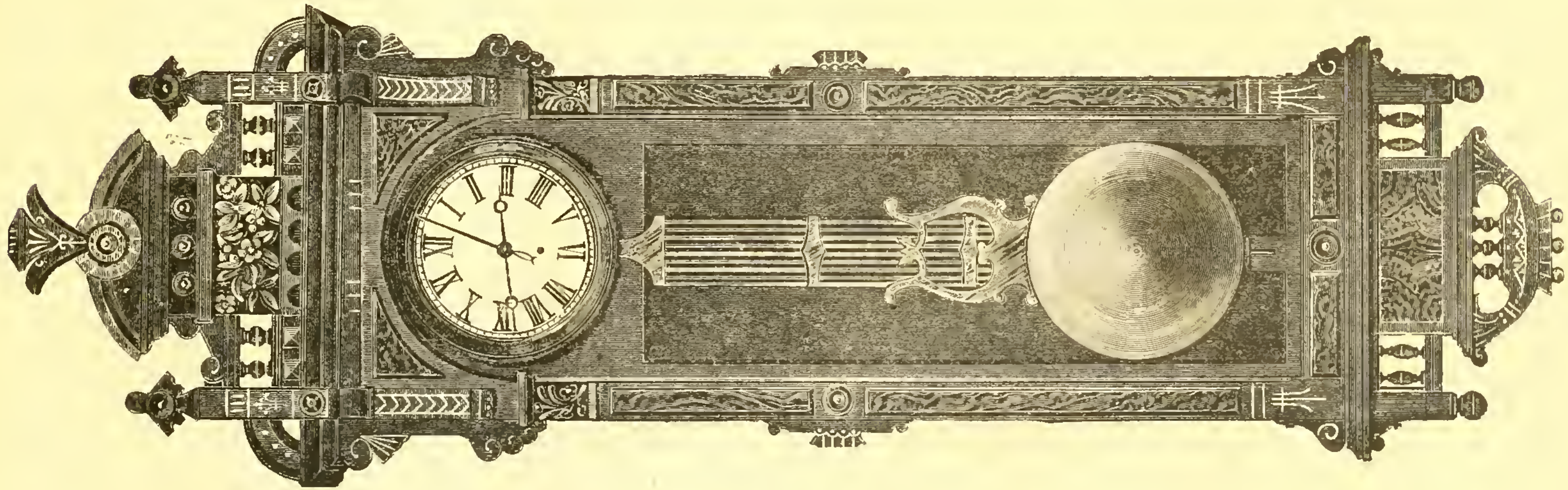

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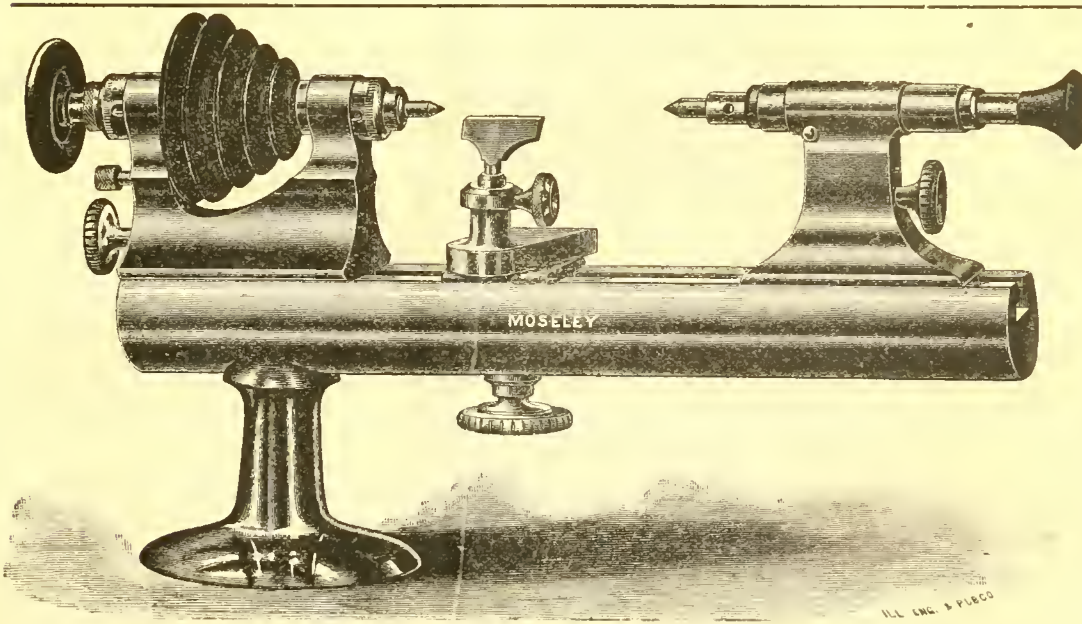

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